1-1-2002

The development of a light-weight brick material

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The development of a light-weight brick material

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF ARCHITECTURE

Major: Architecture

Program of Study Committee:
Bruce Bassler, Major Professor
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Iowa State University

Ames, Iowa

2002

Graduate College

Iowa State University

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INTRODUCTION

People worldwide are looking for new materials to help make their living spaces safer and more comfortable, but which are inexpensive to manufacture and will not harm the environment. For centuries man has used wood for its workability and availability, and brick and tile for fireproofing and solidity. Unfortunately, the availability of wood has declined sharply, especially in the last few decades, because of deforestation and the environmentally destructive practice of clear-cutting. Many brick plants have also closed during this time period because of the change to structural steel buildings, and the labor intensive (thus expensive) process of building with bricks. Masonry labor is also getting more difficult to find. The decline in both of these basic materials leaves a shortfall that modern manufactured materials must fill. Many manufactured materials, though, are not easy to customize once they have been produced, and many have component materials that produce noxious constituents when they decompose (if they decompose at all) or are burned.

The purpose of this paper is to introduce a newly developed building material. Light-weight brick was developed to supplement the current building materials with a material that is easy to form, and inexpensive to produce, and easy to craft once it has been formed. In addition, it is a very good insulator and inflammable and so could be a firewall material.

The producers of bricks and other ceramic building materials could begin to produce light-weight brick with virtually no retooling of their facilities. Furthermore, small kilns could be established to produce this material quite easily - even by the builder of individual homes, as its production involves a very low-tech process.

This paper describes experimentation with processes for producing and developing a light-weight brick material. The first part of this paper deals with the structure of clay and its development from rock as a raw material. The silica tetrahedron, the molecular structure of clay, weathering, leaching, and clay deposits are discussed. These are described to illustrate the differences present in the clays used in the experimentation to develop light-weight brick. Many small differences can change the characteristics of the pre- and post-fired clays and make certain clays more appropriate for further experimentation than others.

The clay section is followed by a section describing the use of burnt earth and ceramics as building materials, the use of which may be traced back to at least 26,000 B.C. Raw earth has been used for millennia, and fired earth since before the time of Babylon. The Czechoslovakian kiln found at Dolni Vestonice is discussed, and the burnt earth bricks used in Babylonia are compared with those manufactured and used in ancient Rome. The laws and regulations pertaining to Roman brick-making are examined. The history of the laws governing the design and development of earthen and ceramic products is necessary to illustrate the slowness of development continuing into the time of the Industrial Revolution and still continuing today. The English processes for brick manufacturing are then considered, and the laws and regulations surrounding the trade in that country, and the abuse of these restrictions. The investigation of history culminates by examining American brick-making, its standards, and the current state of the industry, from which I concluded that American brick-makers today are generally conservative with regard to innovation and experimentation with their products.

The third part of this paper details the process of experimentation in the development of light-weight brick. Extrapolating off of a procedure developed by Dr. Denis Brosnan of Clemson University, I hypothesized that changes to his formula might result in producing a light-weight, easily handled material for use in large panels inside firewalls and other areas where insulation and fire-resistance could be beneficial. The requisite materials are listed, as well as explanations for why certain choices in material preferences were made, such as speed of set, size of inclusions, and the effect of certain elements on the finished product such as calcium, sodium, iron, and so on. The process for combining the materials is described.

Sample bricks were then subjected to tests, including the following: Gradient kiln tests, in which those bricks with fly ash as an ingredient remained under-fired or melted to slag, indicating fly ash is an undesirable component in these bricks; compressive strength tests, which indicated that finer grained materials had better strength than coarser grain products; and tests for heat conductance and resistivity, which indicated that the brick material had an insulative value similar to that of foam insulation board, but that fire damages it far more slowly. Tests conducted regarding the capillary action of the material revealed that the bricks could readily gain an increase in weight of greater than 50% by water absorption, or other liquids. Experimentation on the adhesive qualities showed that the bricks could be strengthened by bonding them to a reinforcing material such as wood. Tests were also conducted on surface treatments for the bricks; these experiments indicated that glazing does little to increase the strength of the material, and that the porous material usually absorbs and thus dissipates the glaze.

The final product was not what was expected. It was too fragile for the outside skin of buildings, but could be <u>very</u> useful instead as an insulating and fireproofing material. These properties and the extremely low-tech method of producing it could make it a valuable material for small enterprises down to and including individual home-builders.

CLAY AS A MINERAL

The structure of clay

A basic component molecule of most of the rock on Earth is the silica tetrahedron; that is, four oxygen atoms arranged in a tetrahedron with a silicon atom at the center to bind them together (the chemical formula is SiO_4) (see Figure 1). The silica tetrahedron is one of the most stable molecules, being unaffected by most chemicals and temperatures at the Earth's surface.

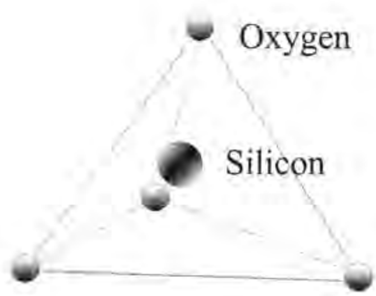


Figure 1. Silica Molecule

When a rock is being weathered, water chemically attacks its molecules. Because water has a natural negative charge, when a water molecule comes in contact with a positively charged atom it will bond with that atom, stealing it from the parent rock. The resulting leftover SiO_4 molecules are no longer part of the crystalline structure of the rock and so are easily moved away from the surface of the rock by the water molecules. The resulting holes left by the stolen atoms weakens the parent rock until it is no longer strong enough to maintain its previous structure. SiO_4 is negatively, rather than positively charged, so water cannot steal its oxygen atoms, and the silica restructures itself as best it can, usually into the sheets that make up clay.

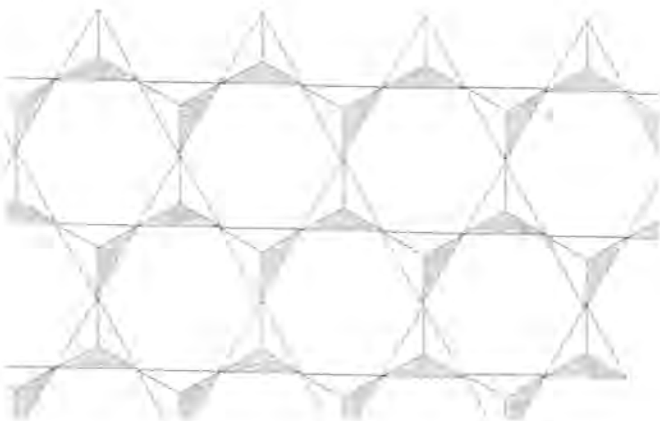
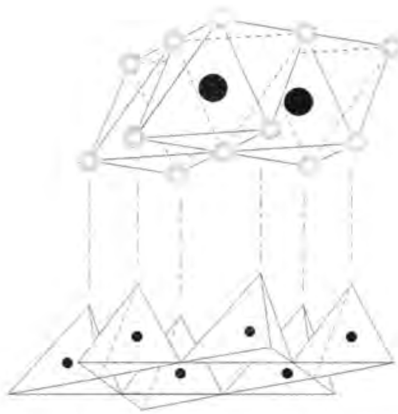
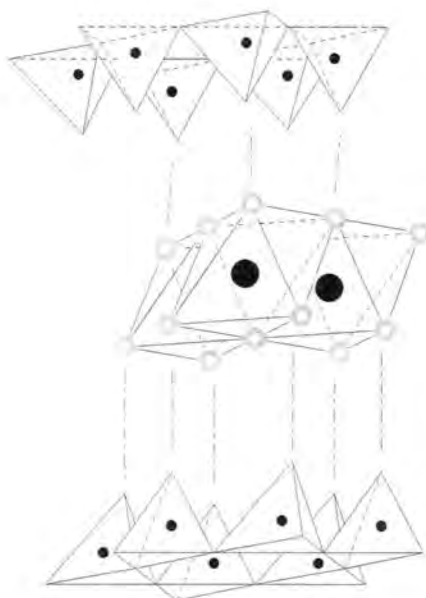


Figure 2. Silica in hexagonal matrix

Clay is made up of sheets of silica separated by sheets of complimentary atoms or molecules. The exact composition depends on where on Earth the clay was formed and what other minerals were there at that time. The silica is arranged point to point in six-sided figures, with the fourth points all heading in the same direction (see Figure 2). The next sheet usually is oriented in the opposite direction so the points aim at the points of the first sheet. Separating these sheets is an octahedral layer of Hydroxyl molecules (HO) with interior atomic ions. Between these couples of sheets there is a space that is filled with water, leached cations and free positively charged ions. Since silica can coexist with dozens of different ions and molecules, there is no end to the combinations possible, but there are general common groups of clays depending on how the silica sheets are arranged and the most prevalent ion in the intervening sheets.



A.Kaolinite -- silica sheet + octahedral sheet



B. Smectite – 2 silica sheets + octahedral sheet

Figure 3. Silica in sheets - exploded view of sheets;

The formation of clay

Each variation or combination of ions in the octahedral sheets depends on the parent rock or rocks and gives that clay a unique set of properties including color, density and firing temperature, though clays in the same group tend to be similar in their properties. Many clays are only differentiated by their interlayer cation or cation group (see Figure 4).

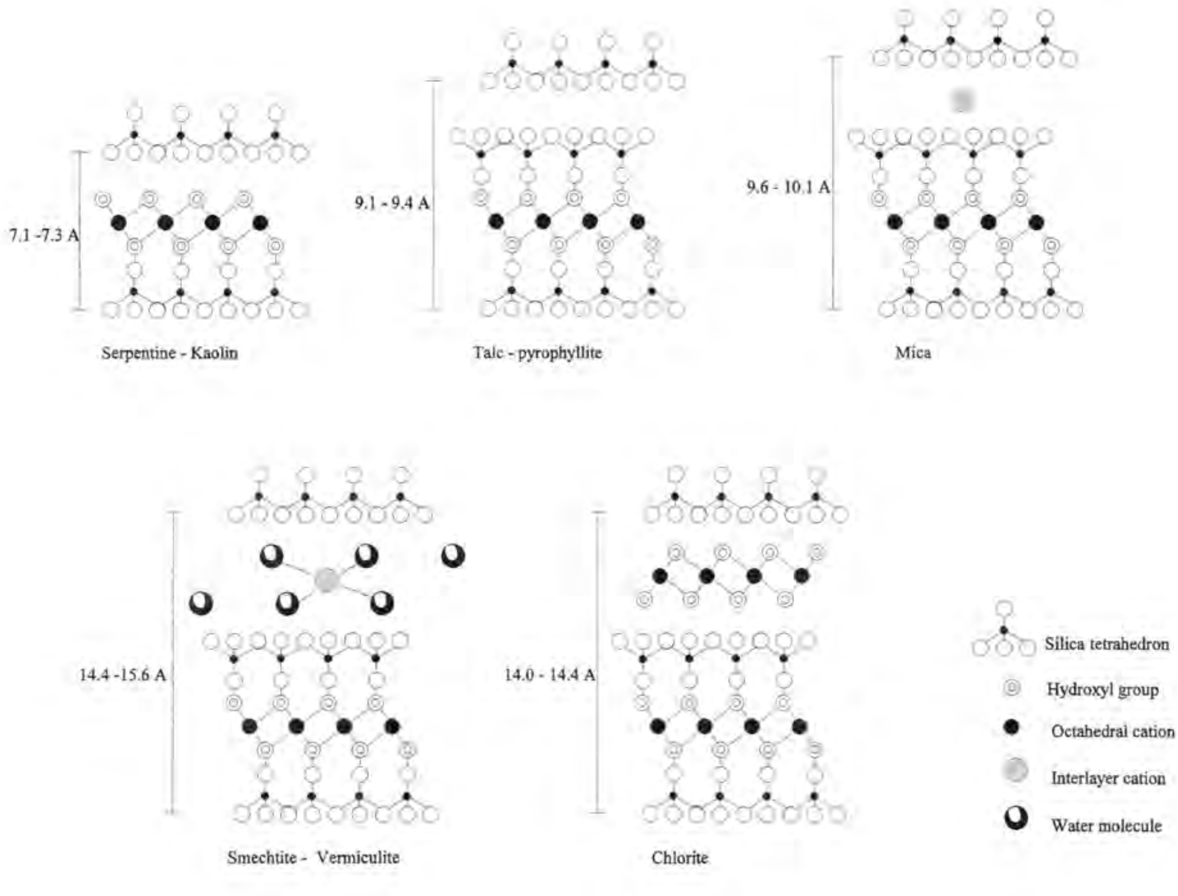


Figure 4. Diagram of major clay mineral groups (Chamley after Bailey 1980)

While erosion by wind or water creates some clays, the majority of clays in the world are formed by a process called leaching. Leaching is the movement of ions out of rock by chemical interaction with water and acidic ions in the water. Areas of high rainfall would naturally have more clay leaching than dry areas. Reduced runoff in important since most leaching goes on under stable soils . For example, rain that falls on Iowa will sink into the ground until it hits rock (small stones start appearing about a yard or so down). When the water touches these stones, it leaches the most positively charged surface ions from them. The water then continues down into aquifers that run under the state. The leached ions eventually end up wherever the aquifer becomes becalmed, either as nodes underground in low spots or in the ocean. The clays that are left remain in place under the soil. As Herve' Chamley indicates,

> The weathering complex tends to evolve with time, and gives a soil that constitutes the natural transition between parent rock and the atmosphere. Clay sized fraction and clay minerals are the major components of most weathering complexes and soils.[1]

Most soils are from 50 to 70 percent clay and clay sized fragments. Surface water, which can move stones as large as boulders at times, has no trouble transporting the tiny, even microscopic, clay particles. Therefore, in flatlands like the Midwest, clay is continuously formed at the soil-rock boundary and carried to the surface by biologic activity or farming practices, and from there transported down rivers (see Figure 5).

Clay from this process is deposited either in beds at the mouth of the rivers, forming deltas, or further into the oceans forming beds on the ocean floor, depending on

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[1]Chamley, Herve, Clay Sedimentology, pg. 22, Springer-Verlag, Berlin Heidelberg, 1989

the size of the clay particles. The smallest particles may settle miles from the mouth of the river (see Figure 6).

Since many clays tend to have similar sizes within their group but are different between groups, different types of clay will be deposited at different distances from the source. Thus, beds of clays of the same type form even though the river has washed many types down to the ocean.

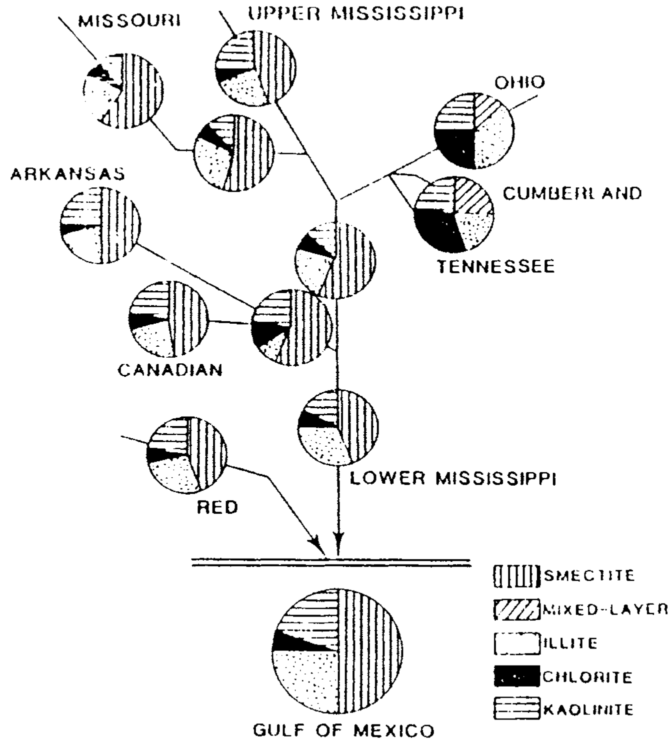

Figure 5. Diagram of Mississippi clays and sources (Chamley after Potter)

During the Jurassic and Cretaceous periods (200-65 million years BC), when the Midwest was covered by a great inland sea, the sea itself was the depository of all the clay being washed off the mountains to the east and west. Great clay deposits were laid, some measuring hundreds of feet in thickness. Over time the lowest of these were pressed into shale by the weight of deposits above. This shale, reconstituted into clay, can also be used by ceramics manufacturers.

In the Midwest, these great bodies of buried clay and shale make up the greatest resource for brick and tile makers today. Most of the brick manufacturers in the Midwest today rely on buried beds of Cretaceous clay. River clays, used by artisans in other parts of the country, are valuable and easy to mine but are rarely large enough to exploit for large scale ceramic factories. Major exceptions are the deposits in the delta of the Mississippi, and other large, slow moving rivers and swamps.

In the Middle East, around the two great rivers Tigres and Euphrates, the flatness of the land insures that whenever the rivers flood (nearly every year), the land for hundreds of miles inland stays underwater for some time. Therefore, clays and sediments in the floodwater are deposited that otherwise would have been swept out to sea. Matson notes that

> The periodic Great flood, such as the one in the tale of Noah's ark, can be all-encompassing and devastating. For instance, Cressey, in discussing the riverine sediment accumulations, quotes Mitchell, who reported that during the 1954 flood 'a lake 70 square kilometers and up to 24 meters deep formed east of the Bund outside Baghdad, which took seven months to drain away and left deposits 30 centimeters thick.' As I drove along the Bund or protective dyke en route from Baghdad to Babylon in December 1954, I could visualize the setting for Noah's experiences. The wet clay was tenaciously sticky. Driving along mostly submerged roads south of the Bund, guided by bordering hedges, was a memorable experience even in a Landrover equipped with chains.[2]

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[2] Matson, F.R., "The Brickmakers of Babylon", Ceramics and Civilization, Vol 1, pg.63

River clays of these and other large rivers were the source of the earliest building bricks, which were made thousands of years ago by beating chaff into the clay. This gave the bricks enough body to hold together until they could be fired. Great Babylon, with its enormous ziggurat and palaces and gardens, was built entirely of bricks made from the clay that had ben excavated to make its moat. Until recently this great pile of bricks had been used as a quarry for many of the nearby towns.

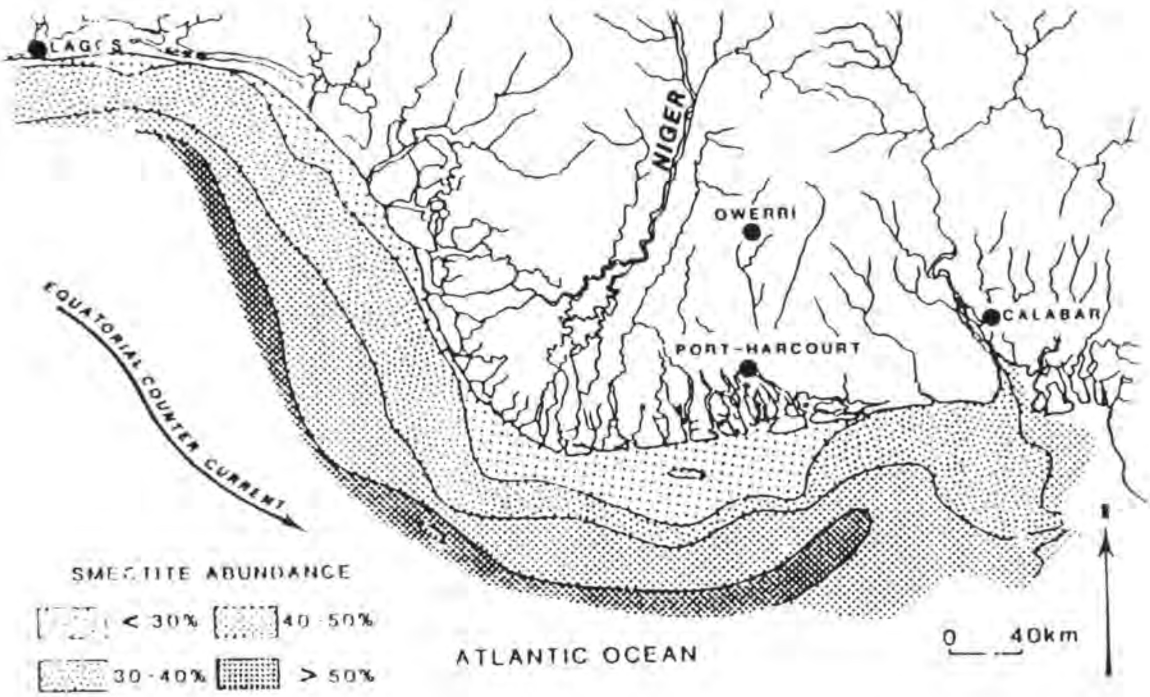

Figure 6. Diagram of clay settling off shore (Chamley after Porrenga)

HISTORY

Earth as a building material

Clay (or earth) was used as a building material ages before documented history. Adobe, or unfired brick, has been found in Mesopotamian buildings six to seven thousand years old. This type of brick is made by mixing wet, clayey earth with straw or chaff and pouring the mix into molds. After a few days, the molds are removed from the clay and the semi-dry bricks are stacked to continue drying. These molded adobe bricks can be very uniform in dimension and therefore easy to design for and build with. Adobe, though, has a relatively low strength and cannot support much more than two or three stories without being crushed under its own weight. Exceptions to this can be made by piling the bricks so that the weight is distributed outward and evenly, as in Babylon's ziggurat where only the outermost layer was of fired brick.

Buildings made of adobe today have walls that are very much thicker than those to which we are accustomed in modern houses. Even a single story adobe house will have walls eighteen to twenty-four inch thick, which at 100 pounds per cubic foot, means that tons of materials have to be brought to the site and placed by hand -- a major disadvantage in this age as it is a very labor intensive form of building. Another disadvantage to adobe houses is that adobe is very vulnerable to water damage. It can only be used in dry climates, and even there surfaces must be patched regularly unless they can be kept entirely out of the rain (as with the Anasazi Cliff dwellers' buildings). Adobe exposed to water damage can decompose in a matter of weeks. Keeping it patched and painted with waterproof materials, however, lengthens its life indefinitely. The

Mesopotamians, for example, used asphalt or bitumen to repair and protect adobe walls, and some of their buildings have lasted for centuries.

A major advantage to adobe is that the walls are incredibly insulative from temperature changes outside. A change of forty degrees outside will make only a few degrees difference inside simply because the mass of the wall holds heat and disperses it slowly. Other advantages include the noise damping effects of such thick walls, natural fireproofing, and the secure feeling of being surrounded by so much material.

In several areas of the Middle East, rammed-earth building is another common form of earthen construction. For this type of construction, clayey earth, usually found on the site, is brought to a large formwork already in place on the building site. Earth is placed in the formwork and beaten down over a period of time, with great pressure, by tamps created for this purpose . When this tamping is completed, the formwork then can be moved further along or up the wall, and the process is repeated to continue the building. Walls formed this way are very strong and may stand for centuries with little maintenance, even in wet climates. For example there are towns in South Yemen made almost entirely of rammed earth construction with homes five or six stories tall. Several large churches in Europe and the United States have also been constructed from rammed earth centuries ago and are still standing, having survived hurricanes and earthquakes (see Figure 7).

Rammed earth buildings are also highly insulative because the mechanics of construction necessitate that the walls be wide enough for people to stand inside the formwork while tamping. Moreover, rammed earth construction has the advantage of being waterproof as well as fireproof. However, a major problem is that it is nearly impossible to regulate standards of construction. The material used is soil of no specific composition and so can vary within a few yards of its origin. Another disadvantage is that because it is a labor intensive type of construction, the quality of labor can vary along

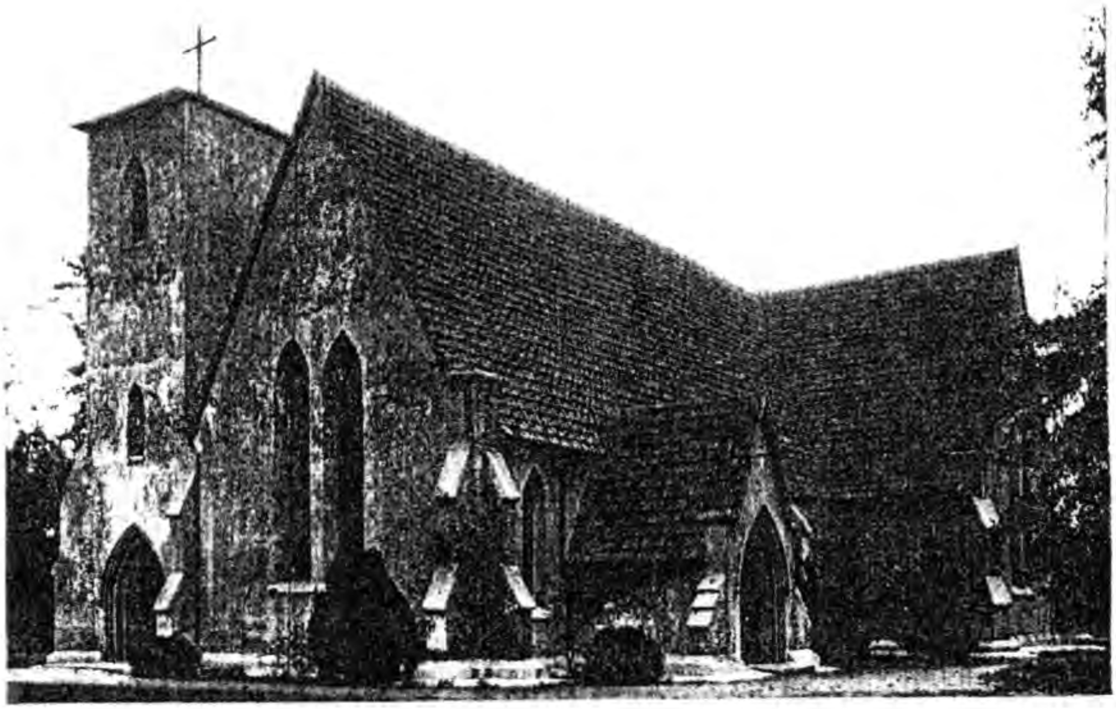

Figure 7. Rammed earth Church near Sumter, SC (Merrill after USDA)[3]

the length of a wall. Minor defects are common and the safety of workers or subsequent dwellers cannot be guaranteed, as they might with more conventional types of construction. Even so, there are standards printed by ASTM (American Society for

3 Merrill, Anthony F., The Rammed-Earth House, Harper & Brothers Publishers, New York, NY, 1947.

Testing Materials) because of the interest in this type of building in this century. During the early decades of the century, several experimental attempts were made to achieve rammed earth building as a common form of construction, notably by Tom Hibben in his Gardendale homes near Birmingham, Alabama (see Figure 8).

However, these attempts failed even though the houses were successful because many people would rather live in houses that were made conventionally and looked conventional. In many cases, the homes that were made and occupied are still in use.

Figure 8. Rammed earth house at Gardendale,(Merrill after Hibben)[4]

4 Merrill, Anthony F., The Rammed-Earth House, Harper & Brothers Publishers, New York, NY, 1947.

Burnt earth and ceramics

The production of ceramics, as burnt earth, goes back at least twenty-eight thousand years into mankind's history. For example, thousands of small bits of pottery have been found near the remains of the ancient town of Dolni Vestonice in Czechoslovakia, around and in an ancient kiln that could fire at a thousand degrees or more Fahrenheit. This kiln was dated as having been built at approximately 26,000 BC. The design of the kiln was very advanced and efficient for making small ceramic figurines and beads.

> There are three requirements for a kiln to reach temperatures required to transform clay into a solid, rocklike mass. They are control of draft, the path of air and combustion gasses through the kiln, to optimize the spread of heat away from the fuel source as well as support for the ware and a surrounding refractory structure which insulates the ware. The two features at Dolni Vestonice do meet these criteria, each having a refractory wall with an opening on or toward one side and directional flow from an opening toward the opposite side.[5]

Such kilns were similar to ancient bread ovens but with added area in the firebox and ventilation designed to direct the heat into the center of the kiln. This kind of kiln could heat the center much hotter than would ever be needed for any food. This indicates that the basic technology for making ceramics had been known and was in common usage for a long time before the Czech kiln was built.

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Vandiver, Pamela B. et al. "Venuses and Wolverines: the origins of ceramic technology, ca. 26000 B.P.", pg 62, The Changing Roles of Ceramics in Society :26000 BP to the Present, Ceramics and Civilization vol. 5, The American Ceramic society, Inc., Westerville, Ohio, 1990.

1)Babylon

Burnt earth bricks were in use by the time Nebuchadnezzer built his great city on the flood plain of the Euphrates river. The cost of firing bricks was very great because of the general lack of wood in that region, so only the outermost layer on a building, the face brick, was fired. The walls, often several thick, were mainly of unfired or adobe bricks protected from the elements by the face bricks and layers of bitumen. Even fewer bricks were fired with a glaze to give them color, just the main gate and a band around the city walls to impress visitors with the wealth of Babylon.

> Herodontus reported that when the great protective, deep, water-filled moat was dug around the city, the workmen made bricks and fired them in kilns as the excavated clay accumulated. The fired bricks were then used to face the borders of the moat and to construct the city walls.[6]

When Nebuchadnezzer died his son built a new city several miles away and Babylon fell into disrepair, eventually being covered by the mud and clay of the flood plain. The glazed bricks of the main gate (the Ishtar Gate, now residing in a German museum, see Figure 9) sat undisturbed by vandals and miners until this century, when the city was rediscovered by archaeologists and the local mining of bricks was stopped by the Iraqi government.

The bricks of Babylon are of remarkably regular size and shape. By this it must be supposed that there was either only one supplier or that rigid laws were in place dictating the procedure for the making of bricks.

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[6] Matson, F.R., "The Brickmakers of Babylon", <u>Ceramics and Civilization</u>, Vol. 1,pg. 63

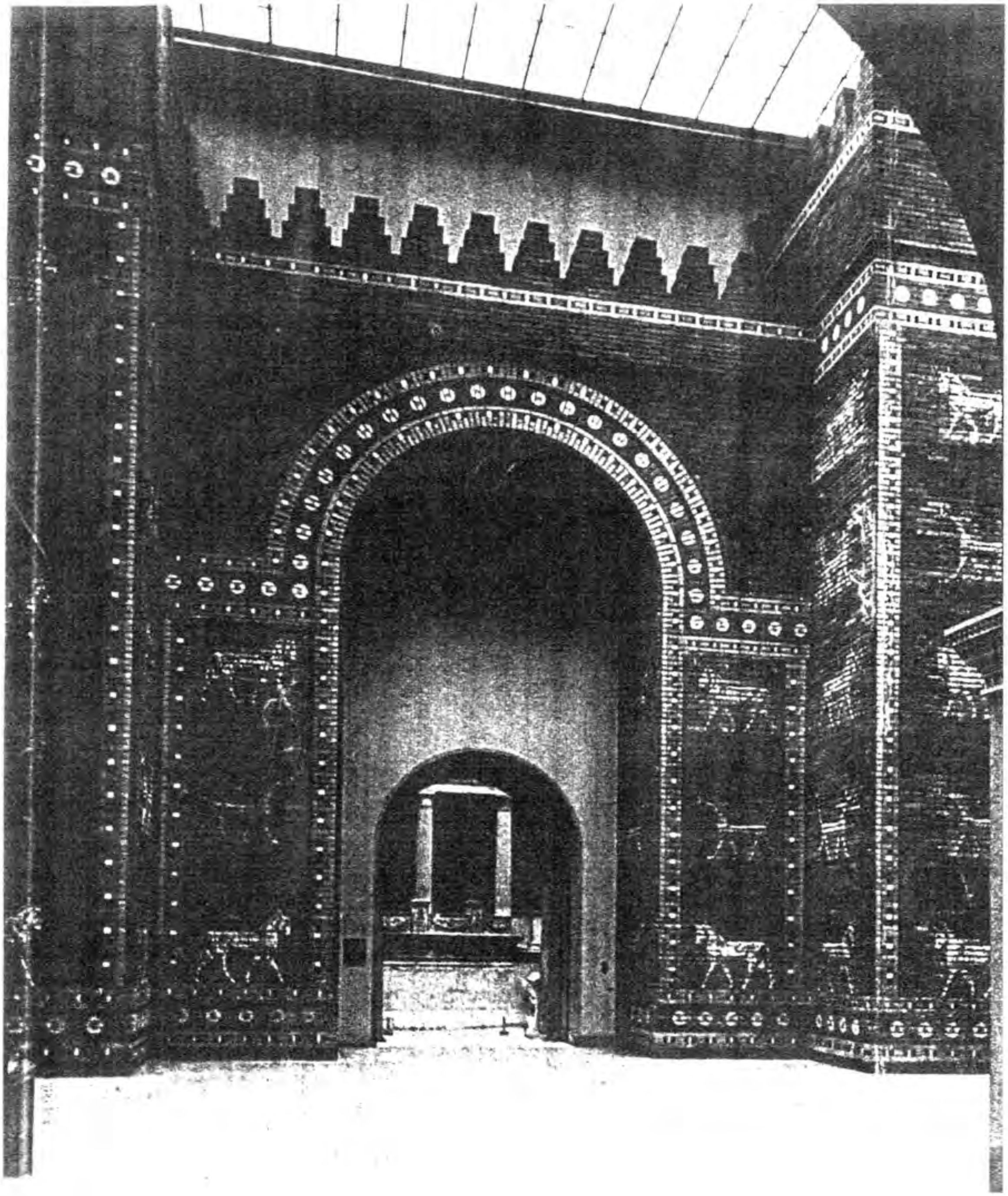

Figure 9. Ishtar Gate of Babylon

2)Rome

Ancient Rome is a city made essentially of brick. After the great fire of Nero's time, the city was rebuilt of fireproof materials most notably cement and brick. Many walls were made of a combination of these two materials -- the core of rubble filled cement and the outside covered with square bricks shoved into the cement in a method called "reticutatum". Later many buildings were resurfaced with stone so that the plebeian brick of the fabric would not show.

In contrast to the evenness of Babylon's bricks, the bricks of Rome vary considerably in length, width and thickness, the result of private contractors trying to get as many bricks as they could out of a weight of clay. That is not to say there were no laws dealing with the sizes of bricks in Rome. The laws in Rome or the enforcement of them was more concerned with the strength of the bricks. Because bricks made without the compacting of modern machinery varied greatly in strength even in the same firing, they ranged from very strong to so fragile they would crush under the weight of a single wall. In addition many of the larger bricks were made so that they could be broken into smaller triangular pieces for making brick-faced rubble walls, which were much cheaper than solid brick walls and therefore very much in fashion.

The bricks in Rome show the marks of many different brickworks and makers. Many conform to the laws of Rome, especially those made for imperial buildings, but many are smaller, showing that the makers, who sold bricks by the number rather than the weight, were concerned with getting as many bricks as possible out of a given quantity of clay. Another problem was the fact that many bricks were measured by the cubit which is the length of the forearm of the person making the measurement. Smaller people would make smaller bricks and taller people would hire smaller people as foremen so that their bricks could also be smaller legally.

3)England

The process of brick making was dispersed around Europe by the Romans as they expanded their empire. Officials of the legions wanted homes and baths in the Roman tradition and imported their own brick and tile makers who taught the local populace. By the seventeenth century in England the process of making bricks was well understood and very much governed by the law. Every aspect was covered, from when the clay could be dug to the arrangement of the brick in the kiln. The only real problem with all this was that Parliament choose the Brick-makers Guild as the enforcing body. This arrangement led to abuses of the system, from waiving fines for friends to neglecting to inspect the bricks of competitors (since they could not be sold before inspection) and to taking bribes for both. Over the years many brick makers complained about their competitors getting off, but at the same time insisted that the addition of "spanish", that is coal ash and other rubbish from the streets of London, would make brick harder and they should be allowed to use it. The arguments of scientists at the time that spanish actually made bricks weaker was generally ignored because of the economics of both the brickmakers and the street-cleaners who would have to carry their trash shorter distances.

As abuses of the law became more common and the complaints grew, the laws in turn became more stringent and the Guild more tight in holding down the competition. In effect no one was allowed to make bricks in any but the prescribed way. If anyone was found to be experimenting with new ways of making bricks or new formulas, or if any of these products were found in the brickyard, even if they were not being offered for sale, a heavy fine would be levied. The Guildmasters did not want anyone making better or cheaper brick than themselves and had the means to enforce their will.

The bricks at this time were made in clamps (temporary kilns made of the same brick that was being burnt) or permanent kilns where there was enough clay, though it was rare in England to have clay more than a meter or so thick. The practice of making bricks in clamps did not make very strong bricks. The brick in the center was well burnt, but the brick in the outer parts of the clamp did not get burnt all the way through and so was often very weak.

> ...the Brick-makers of late years, have made, and continue to make, great Quantities of Clamp Bricks... and, Place-bricks being set on the Outside of the Clamps, they are therefore not well burnt, and are very unsound, and almost unserviceable, and of uncertain Dimensions; to the great Prejudice and Unsafety of Buildings, and Deceit of the Buyers...[7]

Many times this "salmon" brick (called so because of the color of partially burnt brick) was one third to one half of the total in a clamp. Salmon brick was sold legally as a percentage of the brick in a load (a thousand brick) because it was uneconomical to insist that all that brick had to be thrown out or refired. The strength of the salmon brick could not be guaranteed and frequently it was so bad it would deteriorate in the wall in only a

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House of Commons, 28 February, 1725. Quoted in Contributions to a Study of Brickmaking in America, Pt. 2, "Statutes Relating to Brickmaking in England, 1729 to 1777", Claremont, CA, 1963.

few years. This made the frequent repair of buildings a necessity unless the buyer had enough power or money to insist that no salmon brick be used in his building.

The laws of Britain eventually set a standard for the hardness of bricks as well as for the exact size of the bricks. Many builders complained to Parliament about the brick makers because they could not get the large brick they needed to refurbish buildings that had been made before the laws became so strict, and many brick makers complained that buildings could be made very much easier if they were allowed to make bricks slightly smaller.

> John Brown said, That the biggest Bricks are the best; but middle Bricks have been used for these Twelve Years past: That he has measured several under Eight Inches.
> Thomas Fox, Brickmaker, said, That the Brickmakers generally make Bricks Eight Inches and a Half long, Two Inches and a Half thick, and Four Inches broad: That Nine Inches would be too long, and cannot be burnt well.
> John Godson, and Mr. Porter, Brick layers, said, That Bricks Nine Inches long, Four Inches and a Quarter wide, and Two Inches and Three-quarters thick, are best for Service: that they have had very good Bricks of that Size.[8]

4)America

When brick making moved across the Atlantic, the laws of England concerning brick making were brought across as well the mindset that there was only one right way to make bricks. Brick makers raised in the British brickyards would only know the British

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House of Commons 28 February, 1725. Quoted in Contributions to a Study of Brickmaking in America, Pt. 2, "Statutes Relating to Brickmaking in England, 1729 to 1777", Claremont, CA, 1963.

way and would shy away from experimentation. So while the rest of industry in general was going through a revolution, brick makers were only concerned with how to make bricks more uniform in size, strength, and with less waste -- in other words, how to make them conform to the previously set standards of England.

Today across America, bricks are remarkably uniform in size and strength and do indeed conform to the standards set up two hundred years ago. Very few brickyards will offer bricks in sizes other than the standard, mostly because that is what their machines are set up to produce, although that is changing in the ever more competitive market. Even fewer brick makers will offer brick with less strength than the standard as that may imply that their product is less valuable.

When the modern standard (the standard with modern machinery to produce brick) was being established, brick buildings were common and brick as the main load-bearing material was popular, especially for large and tall buildings. That was before steel framed buildings and reinforced concrete became widely available. However, in the 1950-s and 1960s reinforced concrete became the new standard for buildings of size and brick became just the material to cover the outside face of the walls. It no longer has a need to conform to the strength standards set in years past. Interiors and firewalls, especially, no longer need to contain brick that is strong enough to carry vast loads.

Ceramic building materials in America today are basically the same as they were one hundred years ago except that they are being used proportionately less. One hundred years ago there were three hundred brickyards in Iowa, but today many of those brickyards have been closed for lack of business. Now there are only three left. Many of the brickyards that survive in the US do so by offering a unique product -- a special color or bricks specifically to repair historical buildings. Some brickmakers will now produce specialty shapes for their clients.

> One area that has a major impact in the brick market is specialty shapes. Almost every company returning a survey responded that special shapes are increasing in use and are a critical factor in landing commercial architectural jobs....5% to 90% (with an average of 38%) of all commercial jobs require special shapes. Some companies also provide glazed brick in order to increase sales.[9]

Reports on the technological advances in American ceramics indicate that while most fields are advancing at an astonishing rate, architectural ceramics are falling way behind the rest of the modern nations in innovative technology and products. A survey of the brick and tile industry for 1987 through 1991 shows a 4% decline in the value of total shipments[10], indicating a reduction in the number of bricks shipped in that time. This decline should indicate to the producers a need to diversify their product line. Some have done this by catering to the growing demand for special shapes and by introducing new colors or finishes, but others have maintained that such catering is not cost effective -- in other words they do not make as much profit from he special shapes as they do from regular bricks, mostly because of the increased labor needed to hand-shape the special bricks. Many of these same producers do not see the loss of profit is due to the loss of business that goes to brickyards which will cater to the needs of the consumer.

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Greg Geiger, "Trends in the Structural Clay Industry", American Ceramic Society Bulletin, American Ceramic Society, Westerville, OH, Vol. 70, No. 10, 1991.

10 Greg Geiger, op.cit.`

Conclusion

The brickmakers of today are a relatively conservative lot from the standpoint of innovation and new materials and procedures. This would be a reasonable attitude if the need for bricks as a building material had continued in this century, but the change (innovation) in building methods to include steel frames renders brick a mere facing material. Whereas brick today is made to withstand 4,000 pounds per square inch of pressure, the reality of building makes bricks rarely support more than ten feet of non-load bearing wall of 45 bricks, or less than 40 pounds per square inch. Bricks no longer have to be strong, they merely have to be tough enough to withstand the battering they get as an exterior facing material.

Many brickmakers today are finding that, to continue to exist, they have to expand their product line to include materials that do not come up to the standards for strength established with the modern brick making machinery. Hand formed specialty shapes are one example of a material being made that does not meet the standards, but that builders are often insisting upon. There are many other materials that could be made from clay if the brick companies would look for innovation in that arena.

EXPERIMENTATION

In spring of 1991 the research of Professor Denis A. Brosnan of Clemson University in South Carolina was brought to my attention. This included a material he had discovered during the course of his experiments to create an extremely light-weight clay material for use in the Aerospace industry. The formula he used was a disappointment for his purposes in that it could not be made light enough for the aerospace industry. Still, he thought it might prove more useful in ground-based applications, although he did not have the time for experimentation nor expertise in the field of construction to develop it himself. The sample he brought to show me was approximately one third the density of regular brick, the same color as brick, easy to shape after firing, and required no high-tech processes to create. It was clear that with some investigation and work, this could be a highly valuable addition to the architectural ceramic industry. Therefore, beginning with Professor Brosnan's formula and sample of the ceramic, I began a series of experiments.

My original hypothesis was that, with changes in the formula, I could develop a material that could be made in large panels but, because it weighed only one-third to one-fourth the weight of stone, could be handled easier and, as a man-made product, would be of more consistent appearance and without the hidden flaws that produce wastage in natural materials. This light-weight brick could be used instead of stone to face the outsides of tall buildings, or as an insulating and/or fireproofing material inside walls, or as the carrier of liquid for evaporative cooling . Such a product might also be useful in smaller buildings as prefabricated panels that could be set up quickly and cut to fit and with far fewer problems than concrete walls. In addition, the color and texture would be very near that of regular bricks and so could be matched to flooring and accent pieces. Eventually, my experiments lead me to the conclusion that, even though it would not be suitable for outside use, this light-weight material would be excellent as an insulator and firewall, or as an interior facing material. And, because it is so easy to make and inexpensive, it could be put into use by anybody with access to a kiln.

Materials

The original formula developed by Professor Brosnan for this material included clay, a solidifying material, a particulate to add bulk, and various additives to stabilize the mixture.

The clays which I tested were those from the United Brick and Tile Company works at Adel, Iowa; the Sioux City Brick Company at Sioux City, Iowa; and the Endicott Brick Company at Endicott, Nebraska. Each clay had its own qualities, clay structure, and chemical inclusions that made it different from the others. These qualities affected the results obtained in the experiments, but ultimately within acceptable limits.

Clay is, by weight, about one half the solid materials in the formula. It is also the most important part of the formula as it gives the final product its stability after firing and the final color and texture. The percentage of clay should be adjusted somewhat for different clays because of the differing types of clay and the inclusions. Each type of clay has its own firing temperature and final appearance that is determined by the pattern of orientation of the silica sheets and the various ions that separate the sheets of silica. These differences can make a particular clay easier or harder to work with or require more or less particulate or additives to stabilize it. Although the precise formula has to be adjusted for each clay that is used, a general formula can be determined which can then be doctored for individual clays. Most of the formulae I tried are of the general nature, as I was working with different clays and additives. Only the last few were specialized for the particular clay I was using. There is a complete listing in the appendix.

A solidifying material makes the prefired block hold a form. In these experiments I used two materials - gypsum cement or Calcium Ligno-Sulfinate.

Gypsum cement contains a high percentage of gypsum to hasten drying and produce a whiter finished product than normal lime cement. The cement worked very well for the purposes of forming the samples; the blocks jelled within a few hours and solidified completely within a week or so. If it dried quickly enough (within days) there was very little shrinkage, and the dried material could be shaped easily with basic hand or power tools. During drying, though, it was fragile. A disturbance could cause point defects or micro-cracks. Large cracks could propagate from these and spall off chunks or cause the entire block to break up. It was important to find a place to store the uncured blocks that was safe from disturbance and adequately ventilated.

A problem with gypsum cement was its chemical effect on the clay as it was fired. Gypsum is a calcium based crystal which may be broken down with heat into Calcium Oxide (CaO). CaO is attractive to hydrogen atoms in the atmosphere and, if those hydrogen atoms attach, forms $CaOH$. This change involves a threefold expansion in volume which can disrupt the newly forming vitreous structure of the ceramic as it is being fired and can cause pieces to fall off (spalling) or point defects, greatly weakening the ceramic body. "Hydration of CaO results in surface spalling and partial destruction of the samples..."[11]

In my experiments this weakness was experienced as a general brittleness of the material after firing. In addition, the gypsum affected the color of the fired material. Brownell explains

> The fired color high lime and magnesia products is buff, even though the basic clay mineral may be illite. From time to time the light colors have been attributed to the 'bleaching action' of lime; however, this idea leads in an erroneous direction. CaO, MgO, or their silicates have no power to alter the red color of hematite. As a matter of fact, calcium and magnesium silicates are white in color and have no affinity for FeO3. As they become major phases in the product and the silicate crystals grow by continued reaction and sintering, they expel ferric ion oxide into grain boundaries. An examination of the micro-structure will show points of hematite concentration where three silicate crystals join. This isolation of hematite into little pockets within the body causes the macroscopic visible appearance to be pink, buff, or yellow depending on the relative concentration of the alkaline-earth silicates and hematite and on the extent of grain growth.[12]

The color of the fired pieces in my experiments ranged from a light yellow, which was very brittle, through buff to a light to medium salmon which was fairly solid. It

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Klemptner, L.J. and Johnson, P.F., "An Analytical Approach to the Technological Development of Mississippian Pottery",Ancient Technology to Modern Science, Ceramics and Civilization, vol. 1, The American Ceramic Society, Inc., Colombus, Ohio, 1984.

12

Brownell, W.E., "Structural Clay Products", Applied Mineralogy, pg.139, #9, Springer-Verlag, New York, NY., 1976.

seemed to make no difference what had been the normal color of bricks formed from the same clay. The color, therefore, was a direct indication of the volume of calcium in the mix and of the relative strength of the fired material.

The addition of salt to the mixture should counteract the calcium. Klemptner in her study of Mississippian pottery noted that a basic addition to many Mississippian ceramics was crushed shells used to temper the clay (shells are made of mainly calcium carbonate). Many of her attempts to recreate the pottery failed due to spalling until she realized that brackish, rather than fresh, water was probably used. For clay samples that were 15% shell fragments

> Hydration of CaO results in surface spalling and partial destruction of the samples from bodies 01 (no salt), 02, and 03. Bodies 04, 05, and 06, containing 1.0, 2.0, and 5.0% salt, respectively, show some surface spalling and cracking. Bodies 07, 08, and 09, containing 10, 15, and 20% salt, show minimal to no spalling. As the salt increases, the color of the fired sample changes. With the larger salt additions, a dry yellowish surface film appears.[13]

Her experiments show that the addition of salt can alleviate or eliminate the problem of point defects caused by calcium. By her calculations salt at 10% to 15% of the weight of the clay or 30% to 50% of the calcium binder should be used to offset the problem. The surface film is a by-product of the interaction of the salt and calcium. "Clays which contain lime (calcium) in amounts above 3%, especially in combination

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13 Klemptner, L. J., and Johnson, P. F., "An Analytical Approach to the Technological Development of Mississippian Pottery", Ancient Technology to Modern Science, Ceramics and Civilization, vol. 1, The American Ceramic Society, Inc., Colombus, Ohio, 1984.

with iron oxide, produce green to green-yellow glazes"[14]. If this would work for light weight brick the material would be further strengthened by the coating of glaze over and throughout the body. The greatest problem in testing this is that salt is highly corrosive to the insides of kilns.

> From the very beginning of salt glazing, the destructive potential of sodium vapors to brick must have been apparent. Even casual probings of the site of an old salt kiln will reveal brick fragments heavily glazed or spalled (deteriorated due to repeated subjection to high temperatures) to the point of being scarcely recognizable. Until comparatively recent times, salt glazing was considered a process that inevitably led to an extremely short life expectancy for the kiln.[15]

Most brickmakers will not allow such corrosive materials in their regular kilns. A kiln dedicated solely to the testing or production of salt glazed ceramics is needed to test or produce lightweight ceramics with salt included.

An alternative to gypsum cement as a binder is Calcium Ligno-Sulfinate (Cal-LS). This organic material is produced in great quantities in the Midwest to solidify cattle feed into pellets, which makes it relatively cheap and easy to obtain. Cal-LS has the advantage that, exposed to heat, it solidifies the clay block completely within an hour. This prevents the settling and shrinkage that occurs with the clay-cement mixture and prevents cracking that may occur from moving or warping the molds. With access to a heat source capable

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Troy, Jack, Salt Glazed Ceramics, pg. 53, Watson-Guptill Publications, New York, NY, 1977.

[15]Ibid

of sustaining 200+ degrees F, this additive worked very well, and dried much quicker which made it ready for the kiln sooner. The blocks I made with this binder worked as well as those made with gypsum cement and were somewhat lighter. The greatest disadvantage to this material is that it also contains calcium, which produced the same unfortunate results to color and solidity as did the gypsum cement mixture.

Most of my trial blocks came out of the kiln in fine shape, even though I used a calcium binder without adding salt. Approximately 10% broke during firing and another 10% were too soft to use. This indicates that salt would have helped by reducing wastage, but was not absolutely necessary to produce usable material. I decided to concentrate on the formula that used the gypsum cement which was the binder that better suited my situation at the time of my experiments. That either formula (and others with other binders) would work is the most encouraging aspect of this investigation. It means that anybody with access to a kiln or who can make a kiln can make this product inexpensively and without a lot of trouble finding materials. Use of a binder without calcium would increase the strength of the material without changing the other properties.

A particulate was also included in the original formula. This would be an additive that would bulk up the material without adding any chemical reactions to the burning. Fly-ash, the solid residue of coal firing furnaces, was described as an appropriate additive in the original formula. Fly-ash had the advantage that, as a potentially hazardous material, it was unwanted waste to the power plants that produced it and who were happy to see a potential for removing it from the environment. In addition, there is an exothermic reaction when exposed to water, which greatly sped up the solidification process when Cal-LS was used as the binder.

My experiments, though, found that fly-ash raised the sintering temperature (the temperature at which clay crystallizes into brick) above the melting temperature. The experimental pieces went from soft, underfired brick to slag without going through a phase that was solid enough to be useful. Varying the calcium content (the binder) did not produce noticeable differences in the results. These results (I later learned) match the decisions of seventeenth century Parliamentarians in England who decreed that the addition of 'spanish' (coal ash) was detrimental to making brick of workable strength. Yan, et al. have looked more closely at the composition (and therefore the safe disposition) of fly ash.

> Composition of residual ashes depends on the operating conditions of the incinerator, content of feed materials, scrubbing agents and filtration condition.... An equal mixture of both ashes, due to the very high content of calcium in the bag ash, always results in a chemical composition with high CaO content. High concentrations of CaO usually does not produce a stable glass.[16]

A variety of other particulates were explored. These were fine grained material that would burn out of the blocks during firing, leaving air pores, thus lightening the block. Several alternatives were considered: ground corn husks, ground pecan shells, Perlite beads (an additive to concrete), ground corn stalks or hay, sawdust, etc. Of these I chose sawdust as the most readily available to me for experimentation. Both fine (less

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Yan, Qiuming, et al. “Vitrification of Incinerator Ashes” Environmental and Waste Management Issues in the Ceramic Industry II, pg 17.

than 2mm long) and coarse (4mm to 10mm long) sawdust was tested. The resulting blocks differed in texture and extent of damage from point defects. The coarse sawdust produced pores of such large dimension that the blocks strength was reduced considerably from point defects compared to the blocks made with fine sawdust. (See the section on the compressive strength test).

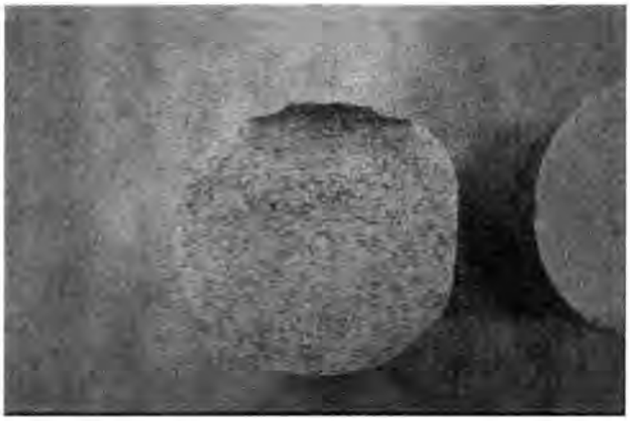


Figure 10. Course-pored brick

The fine sawdust produced a texture that was both very consistent and agreeable in appearance. From this I concluded that a fine textured particulate would perform best in this material, making more, but smaller pores per weight. Any fine, burnable material will be acceptable in this function. The particles should not be too small, or too few, or the holes they leave will not connect to one another. In that case the pores will be filled with gas under pressure which may burst from one pore to the next creating tiny defects in the structure of the material. The pores should therefore be from about .5 mm to about 2 mm. A mixture will create the closest packing of the pores and so the best chances of the strongest material. A particulate that is not uniform in size is therefore recommended.

Polyester fibers were added to the mix to increase the number of pores and to connect the pores to each other and to the outside of the block. They also stabilize the block during drying so as to reduce cracking. These fibers are of hair width and one inch length and are normally used in concrete to increase tensile strength. They can be obtained at lumber yards that cater to small scale contractors and builders. The polyester burned out with the sawdust, the channels it made giving an exit for the gases produced when the block was fired. These are not absolutely necessary, and trials made without them seemed to be fine, only slightly more prone to spalling. Any other fine, fibrous, burnable material would also work.

The liquids added were water, a foaming agent, and sodium silicate. The water was tap water, hot if Cal-LS was used to help the setting process. Water produces a slurry so that the mix could be easily poured into molds to produce blocks of the appropriate size and shape for my experiments. Pouring was preferable to pressing (as is normal for bricks) because pressing squeezes the air out of the mix, reducing the number of pores and the volume of the material. More air pockets were made possible by pouring.

Several foaming agents were considered: vinegar and baking soda, Sodium lauryl sulfate (the air entrainment agent used in concrete), fire extinguisher foam, and seltzer water. These last two were decided against because of the relative instability of the bubbles produced. Sodium lauryl sulfate was used in several experiments, but did not produce the volume of bubbles expected or needed. Vinegar and baking soda were tested, but also had difficulty in maintaining a foam until the material could set in the cement mixture. In the Cal-LS formula the vinegar reacted with the fly ash producing additional heat which solidified the mix before it could be poured. This happened before the vinegar could react with the baking soda and so was too quick for bubbles to form.

In the end, the bubbles formed in the mixing process and those made by the burning out of the particulate were used to produce the voids needed to make the material light-weight. Of these the burn-out voids were easily the greatest in volume. These were enough by themselves to reduce the weight by two thirds.

Sodium silicate is a liquid used by brick makers to control the shrinkage in bricks during firing. I also used it for the same purpose in my experiments. Controlling uneven shrinkage during firing is important in preventing planes of weakness that would produce spalling or cracks in the finished block. It worked for the same purpose in my experiments at approximately 1% of the clay mass. This material seemed to be a good addition, but not strictly necessary. Many of my experiments worked well without it, but it did help in those where I used it.

Process

The process of making the blocks used for my experiments is one of extremely low technology. First, mix the main dry materials - the clay and dry binder together, then add the polyester fibers, and mix thoroughly so that lumps do not occur and the fibers do not clump together.

Second, in a separate bucket mix the liquids together. The clay mix is then slowly added to the liquid mix and well blended, using the beater from a food or paint mixer or other agitating devise attached to an electric drill to blend and stir up clay that settles to the bottom of the bucket. Solid to liquid insures that lumps are not left in the corners of the mixing container. The beater also added air bubbles to the mix.

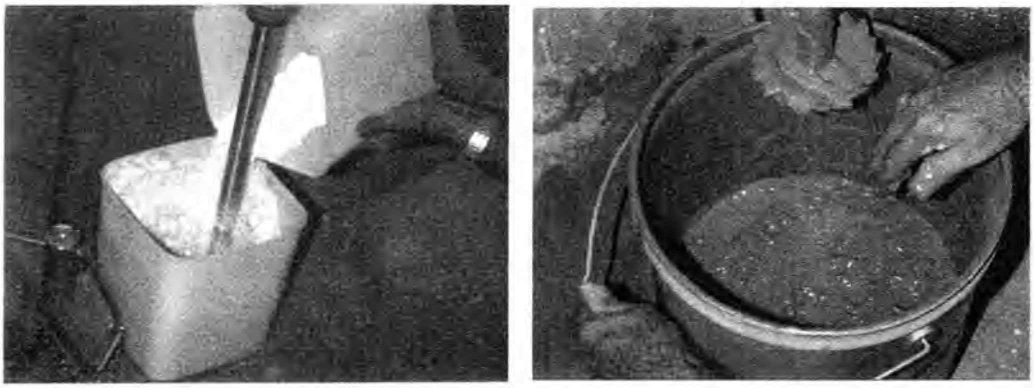


Figure 11. Mixing

Third, the sawdust is added until the mix is the consistency of oatmeal -- thick, but pourable. If the mix is too wet, water will run out the bottom of the form and the mix will lose more volume than expected in the drying process. If the mix is too dry, the possibility of large air bubbles (thus large voids and point defects) becomes too much of a danger. The sawdust in my experiments was measured after it was added by weighing what was left from a pre-measured weight. By volume, the sawdust was nearly half of the dry materials.

The most successful formula was:

Clay (Adel)	3600 gm
Gypsum Cement	1200 gm
Polyester fibers	8 gm
Water (cold)	3600 gm
NaSil	36 gm
Sawdust (fine)	1770 gm

The other formulas and the results are listed in the Appendix.

Pouring the material into the mold was easy, because of the consistency. It could quickly be pushed into the corners and smoothed off the top of the mold. If the Cal-LS formula was used the mold was then put into an oven to heat for 6 to 8 hours at 250°F. If the cement formula was used, the surface was covered with cardboard to prevent surface damage and the mold was put somewhere warm and out of the way to cure and dry for seven to fourteen days. When the material was solid it was removed from the mold for further drying, either by sunlight or in the drying room at the United Brick and Tile plant in Adel, Iowa. All of the blocks were then sent through the United Brick and Tile kiln atop a cart of regular bricks to be burnt at about 1900°F, depending on the particular load at the time. Since they were sent with a regular load, they received the slow warm-up and the cool-down that normal bricks get. This is necessary to prevent the shattering which could occur from thermal shock.

After the basic processes were determined, each variation in the material mix was subjected to this same basic process. The low-tech aspects of this process are very important in that they can be easily copied and used by brick companies operation today without extensive renovations or capital outlay. Alternatively, individuals with an area to dry the blocks and a access to a kiln (even a small, homemade one) can make this material.

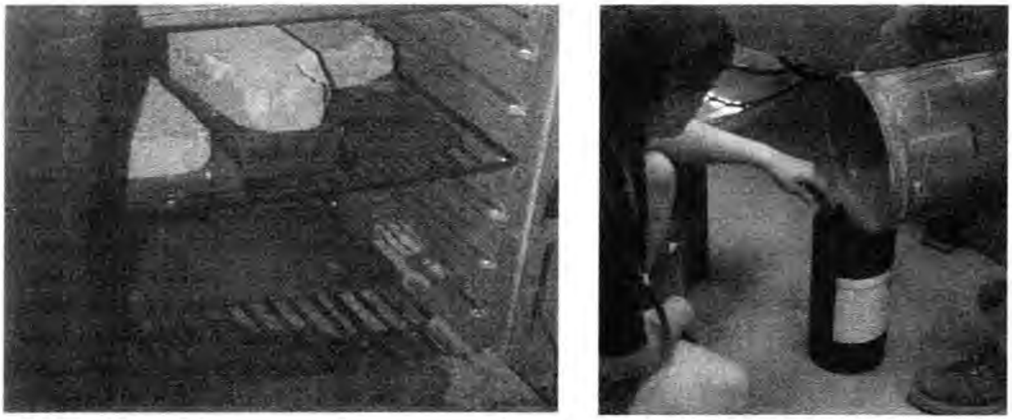


Figure 12. Drying oven and pouring

Molds

The first molds I used were made from disposable metal cake pans lined with cloth to draw the water out from the bottom of the pan. These worked very nicely for small pieces. With these molds I determined the best basic formula. After that the molds were made of wood (because I could control the size of the samples) with the exception of the cylinders for the compression strength test, which were standard concrete test cylinders.

The cylinders for the compressive strength test were used to give a comparative strength relative to the strength of concrete. The cylinders I used began as standard plastic cylinders for the testing of concrete. Their dimensions were 12"long x 6"diameter.

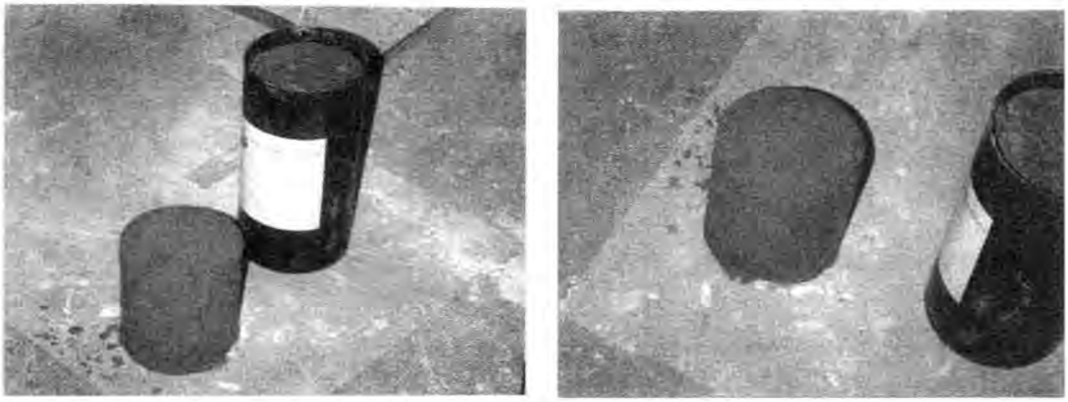


Figure 13. Test cylinders

In the first try in a cylinder of this type, I made no alteration to the cylinder itself, with the result that the material never dried because the water was trapped under a dry film of clay at the top and had no other exits. The next cylinders I drilled through the bottoms in a number of places and placed cotton cord (twine) through the holes to wick the water from the bottom of the formwork. These also were lined with cotton fabric to help wick the water from the sides of the material. These worked very well except for the slumping of the fabric before the mix was entirely in the mold, which made wrinkles in the sides of the blocks. My final cylinders had wicks through the bottom covered by a fabric to prevent the material from encasing the wicks and a newspaper liner for the rest of the mold to pull water from the sides and to extend the height of the mold, which made up somewhat for the shrinkage. These worked extremely well - they were relatively easy to obtain, the materials were very inexpensive and readily available, and they made cylinders of material that were smooth and virtually the same size (11.5" x 5.34") as the concrete cylinders to which they would be compared.

The wooden molds had inside measurements of 1"x12"x12", 2"x8"x12", 2"x6"x40", and 6"x36"x36". The small 2" deep mold could be subdivided into three brick sized pieces by the addition of 1"x2" boards. The smaller molds could fit inside the oven for drying if needed, the large molds had to be air-dried. These molds were prepared for pouring by lining them with a cotton fabric or newspaper. This aided in the movement of water around the block to the outside of the mold and helped remove the dried block from the mold. Cloth liners were reusable and worked fairly well if they could be tacked to the outside of the form to keep from slumping during pouring and settling. Newspaper liners

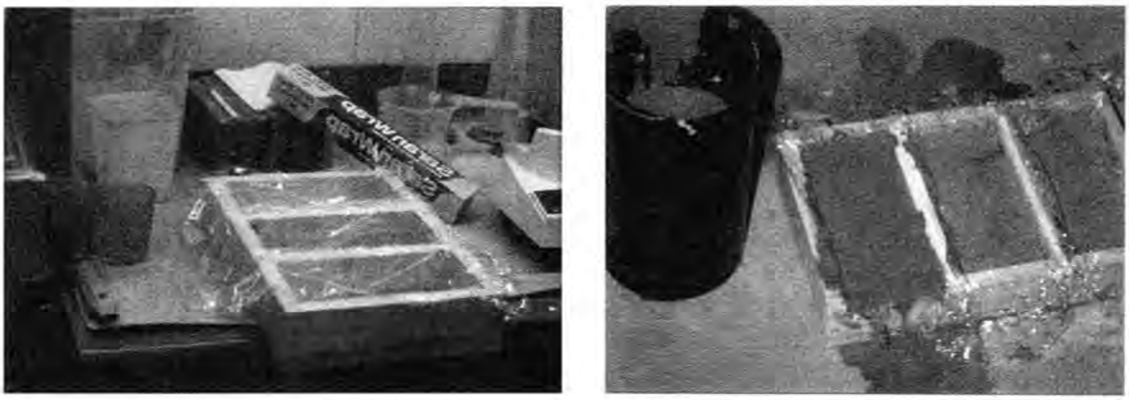
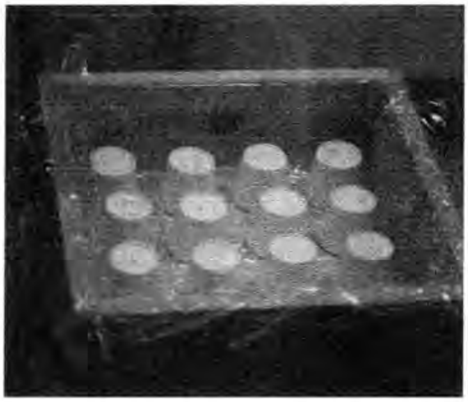


Figure 14. Lined brick-sized molds

are cheap and easy to obtain, and could go into the kiln still wrapping the block. The liners could not be used to pull the block from the form, though, as that always produced an uneven pressure which damaged the block. The best way to remove a block from a wooden form turned out to be lining it with newspaper and then removing one side of the form when dry. It was not too difficult to build forms with one or more removable sides.



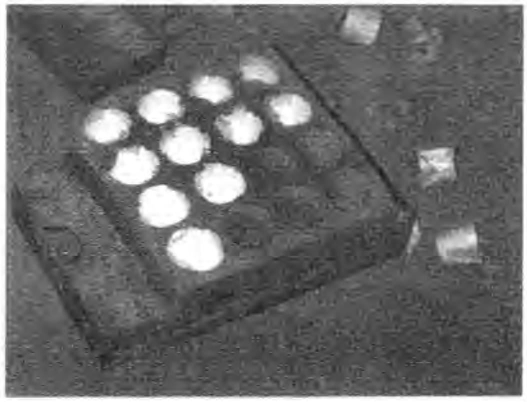


Figure 15. Inserts in 6" deep mold

Several times I also tried inserts in the mold to further reduce the mass of the finished block. I used small boards covered by liners or plastic cups or egg cartons which would burn out in the kiln. These inserts had a tendency to float off the bottom of the mold and so had to be taped down. Also, if there was much shrinkage in drying, these inserts were the start points of a great deal of cracking. The material is easy enough to work after firing that areas could be drilled out with little trouble if even less weight was needed and the waste material added back into the clay mix for the next batch or discarded (it is environmentally safe).

The blocks of all sizes were fairly fragile before they were completely dry, the large pieces especially so. Any disturbance could produce point defects or warp the molds, thus producing micro-cracks. Either of these meant that each block could have an invisible point more fragile than the rest of the block in general, and cracks could start there and progress outward producing breaks or spalling. Micro-cracks became major fractures upon firing and often blocks came back from the kiln in pieces. An interesting example of this is the break in one of the larger, otherwise solid blocks that ran both ways from a small cat paw print.

Experimentation

1)Gradient Kiln Tests

A gradient kiln was used to help determine the best formula to use to make light-weight brick. A gradient kiln is a furnace that fires at a range of temperatures along the length of a single sample. The heating element is located at the center of the kiln and the ends of the cylindrical space are open so that the firing temperature will range continuously from the high at the center (in these tests 2000°F) to near room temperature at the outside. Thermocouples are located along the length of the cylinder to more accurately track the temperatures.

These tests were necessary because the brick kiln at United Brick and Tile fires at 1900F to 2000F. Each of the chemicals in the mixture altered the firing temperature to some degree, so by varying the formula I could determine what produced a viable sample in the appropriate range of temperatures. Samples of the varying mixes were cut to 1cm x 1cm x 20cm to fit the aperture of the gradient kiln. They were then fired for a period of six to eight hours. Samples were allowed to cool slowly overnight before removal from the kiln. This prevents shattering from a sudden temperature change.

The findings from these tests were very important to subsequent experiments. My first finding was that all of the samples that contained fly-ash melted to slag at about 2000°F and just below that temperature remained under-fired (inadequate sintering). This showed that fly-ash was unacceptable as a part of this material and that a different particulate was needed.

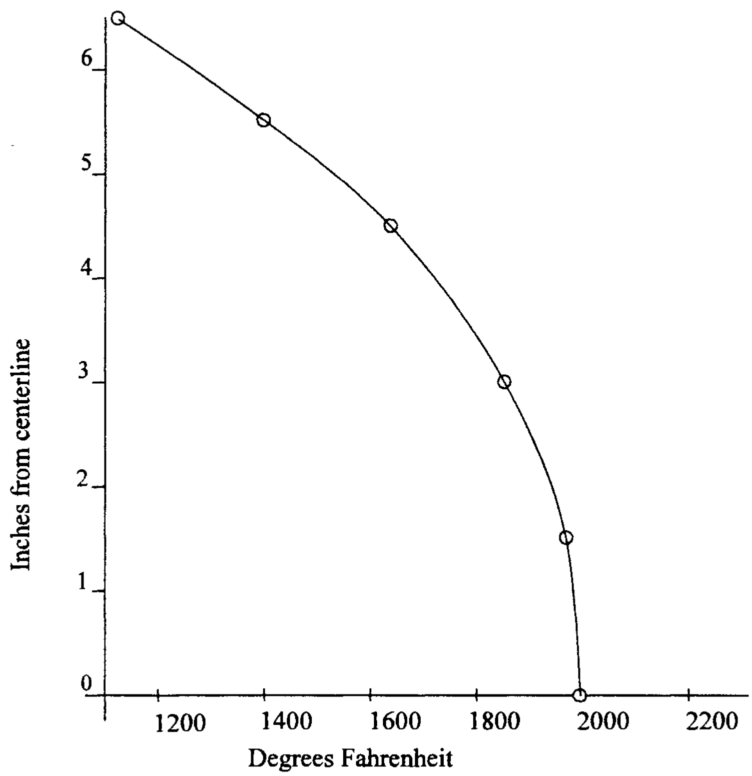


Figure 16. Gradient Kiln test - Sample 31, #2

The clay from Endicott produced a reasonable color and sintered to a hard brick, but at 1850F, which temperature was too low for the kiln at Adel. By 1900°F it had slagged. The clay from Sioux City did not sinter in the range of the gradient kiln, indicating it needed a higher firing temperature than was available to me. The clay from

Adel was sintered in the appropriate range, but in a narrower band than that which the kiln was normally run (the kiln is run at different temperatures to produce different effects in the bricks it produces). This indicates that the material I was producing was more temperature-sensitive than the clay from which it was made. I was able to narrow the acceptable range of temperature to 1930 - 1970 degrees Fahrenheit. Knowing this range allowed me to choose which bricks to send my samples through the kiln with, and know that they would not be damaged by excess heat, and would be fully sintered.

2)Compressive Strength Test

The test for the compressive strength is one of the most common tests for materials. In this test a standard size cylinder of the material in question is placed in a pressing machine that measures how many pounds can be placed on the cylinder before it breaks. The machine I used was a hydraulic press owned by the Civil Engineering department at ISU and regularly used to test the strength of materials (ASTM C39 Standard test Method for Compressive Strength of Cylindrical Concrete Specimens).

For my test four cylinders were poured and fired. The molds used were standard cement cylinders (12"x6"d) modified to drain off excess liquid and with paper inserts to extend the length to counteract the effects of shrinkage. The formula used to make these cylinders was identical for all four except that in two cylinders I used coarse sawdust and in the two others fine sawdust. The two sizes were used to determine the effect of larger pores versus small ones on the strength of the material. The coarser sawdust absorbed less water than the fine, resulting in a wetter but more voluminous pre-fire product. During firing the coarser grained blocks shrank significantly more than the finer grained, with the result that both mixes had nearly the same density after firing. Since density plays a part in compressive strength it was important to compare blocks as nearly identical as possible. This shrinkage was fortuitous in that regard.

Of the four cylinders poured, one each of the large-pored and small-pored had a significant melt on one side (the heat of firing had slagged a stripe down one side). These two were judged to be too damaged to be useful for this test. The other large-pored cylinder had a thin melt stripe and the fine-pored cylinder had no melt damage. These last two were chosen to be crushed despite the slag on the one (which should have made that one stronger). The ends of the chosen cylinders were leveled and sanded flat to accommodate the press, and measurements taken on height, weight, and circumference.

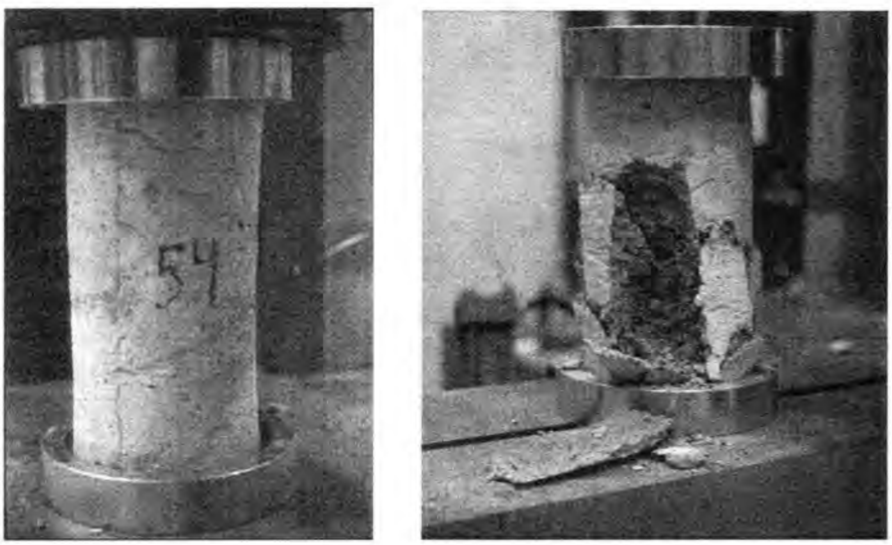


Figure 17. Coarse-grained cylinder with melt

	No. 50	No. 54
Pore size	fine	coarse
Circumference	17.5 inches	16.75 inches
Radius	2.79 inches	2.67 inches
Area	24.37 sq. inches	22.33 sq. inches
Height	10.5 inches	11.5 inches
Weight	7.54 lb.	7.75 lb.
Density	50.3 lb/cu. ft.	50.15 lb/cu. ft.
Melt	no	yes
Pressure	4290 lb.	1830 lb.
Strength	176.04 lb/sq. in.	81.95 lb/sq. in.

Strength is measured in "Pressure divided by Area" -- in this case pounds per square inch.

The results of these tests show that the finer grained material had far better strength characteristics than the coarser grained even with the melt stripe to add strength. Neither cylinder came near to the expected (hoped for) strength of 1000 psi. (Concrete has a strength of 2000 - 7000 psi, brick has 4000 - 12000 psi)[17]. Point defects caused by the holes left when the sawdust burned out were almost certainly the reason for the greatly diminished strength.

A point defect is a place which for various reasons is greatly weaker than the surrounding material. This defect can be a natural part of the material, such as a place

[17] Uniform Building Code Table 24-C

where crystallization has damaged the amorphous structure of the brick, or it can be from an outside source such as a hole poked into a drying block. In the case of the coarse grained material large holes were left in the material when the coarse sawdust burned out. Further weaknesses might have occurred if some of the sawdust was completely surrounded by clay without air ducts to the surface -- the expanding gases produced by the burning wood would blast a hole to get out. The material surrounding these holes acts like bridges across them but grows weaker the longer the span (the larger the hole). A material with one large hole is likeliest to be affected starting at that hole. A material which has many large holes has many places for the defects to start and so is much weaker than a relatively more consistent material. That the small grained sample had the better strength shows that the defects in it were not nearly so disruptive as the defects in the large grain sample. This implies that the smaller and more consistent the particulate, the stronger the resulting material will be.

Figure 18. Coarse-grained vs. fine-grained after crushing.

It is this lack of strength, though, that makes the material so easy to work and form after it is fired. The test cylinder was leveled with a hand saw and sanded flat in under 1 hour. This ease will be valuable for those times when a piece of material will have to be adjusted after it reaches the building site. The material can be cut to size and finished with hand tools or simple power tools.

3)Heat Conductance and Resistivity

The test for heat conductance and resistivity is also one that is commonly made for building materials. It is important to the total insulative value of a wall system. For this test a mechanism was constructed by Ryan Lester, at student in the department of Mechanical Engineering at Iowa State University, that would test the speed at which heat flowed through the light-weight brick compared to how fast it flowed through a material with a known conductivity, in this case copper. The mechanism built is what is known as a guarded hot plate, although it was not to the exact specification of the Standard ANSI/ASTM C177-76 (Standard Test Method for Steady-State Thermal Transmission Properties by means of the Guarded Hot Plate). A hot plate whose temperature could be precisely controlled was placed on the bottom of a stack that was a 1" x 6" plate of copper, a 1" plate of the test material, another 1" plate of copper and a 1" plate of aluminum. This was all surrounded by insulation so that little of the heat would be lost to the environment. The stack was then surmounted by a tank of water kept at a constant temperature. Between each layer was a thermocouple to measure the temperature at that point in the stack. The plate was turned to 135 °C and the tank filled with tap water that kept recycling to keep the top of the stack at 20°C. The stack was allowed to reach a steady state in temperature, and then calculations were made to determine the conductivity of the test material. Copper was used for this test because it has a well known conductive value. The more conductive the test material was, relative to copper, the smoother the graph should be.

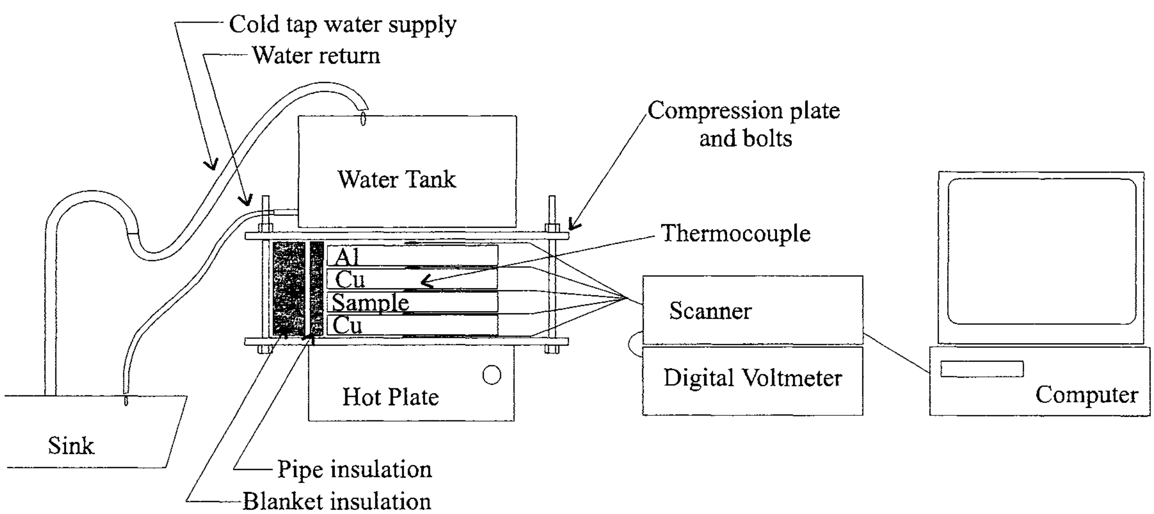


Figure 18. Apparatus for heat - flux test

After reaching a steady state the temperatures in the stacks were...

top of Cu 18.24°C

> change of T 1.05°C

top of Br 19.29°C

> change of T 115.03°C

top of Cu 134.32°C

> change of T 1.25°C

at hot plate 135.57°C

From this example it can be seen that the light-weight brick is approximately 100 times as resistive to heat as is copper of the same thickness. Calculations indicate that the light-weight brick material has an insulative value very close to that of standard insulation board. More tests should be conducted to compare it directly to such insulating materials.

A different test was also conducted to compare light-weight brick to other brick materials. A common brick, a firebrick, and a brick sized piece of light-weight brick were tested simultaneously. Nails were stuck onto the underside of these bricks with wax (melting point 2201F) at 1 inch intervals. The ends of each of the bricks were then heated with a propane burner at one end (1200 - 14001F). The times when each of the nails fell because the wax holding it melted, was recorded.

	1"	2"	3"	4"
firebrick	4 min	10 min	35 min	120 m
common brick	10 m	25 m	85 m	150 m
l-w brick	7 m	45 m	150 m	300+ m

The experiment was stopped after 5 hours with the last nail on the light-weight brick still attached.

A further experiment was made to determine the ability of light-weight brick to resist fire. A small block one and one-half inch square by five inches long was subjected to the flame of an acetylene torch for a period of ten minutes. The temperature at the point of the flame was estimated to be 2000F (the temperature that this material would melt in the kiln). After ten minutes a dime sized area of melt appeared as a black liquid that cooled quickly to glass. This melt was less than one-sixteenth of an inch thick, although the depth of the material destroyed was about twice that. The block was examined immediately. It could be picked up by hand less than ten seconds after the torch was removed. The area less than one inch away was room temperature, and the area less than one-half inch from the melt was only warm to the touch. This shows that heat travels very slowly through the material and that fire damages it much more slowly than it damages common insulating materials. As a fire resistive material light-weight brick is highly successful. The many pores through the material quickly drew away and dissipated the heat before much damage could be done to the material itself. Furthermore it does not melt at relatively low temperatures like polyurethane foam or fiberglass, nor does it give off noxious or toxic fumes as it melts. This could be highly useful for interior firewall construction.

4)Capillary Action

Capillary action is the ability for a material to draw liquids upwards into itself from a pool below. Connecting pores of small size will naturally cause the surface tension of a liquid to creep up them, like water creeps up the edges of a glass. The smaller the pore the higher the liquid will climb. Materials with many small holes can act like sponges.

In my experiment a block one and one-half inch square and five inches long was placed in a dish of water. In eight minutes the water had climbed four inches, and in five more minutes the water had reached the top of the block. This block went from 220 grams dry weight to 340 grams wet weight -- an increase of more than 50%. For architectural purposes this propensity of light-weight brick to suck up liquids is important in that for normal outside uses an increase of 50% every time it rained could cause a possibly dangerous stress on the system by which it was attached to a building. To be used outside a surface coating of some sort would have to be applied to completely waterproof the material.

On the other hand, in dry, hot climates there is often a desire to cool a building without the expense of mechanical air conditioning. Evaporative cooling has been considered when small buildings need to be cooled. This material that could draw water from an underground reservoir and release it to the air thereby cooling the building.

In another experiment with capillary action a small block 1" X 1" X 4" was placed upright in a dish of lamp oil one-half inch deep. In five minutes the oil had climbed to the top of the block and could be set on fire. The flame sat on top of the block, pulling more oil up and only after one minute did the flame creep to the edge of the top and start down the sides, whereupon it was put out. If a ring of inflammable material were inserted to stop the flame from creeping, the block could have been kept burning indefinitely with the block acting as a four inch wick. The slight heat from the small flame did no damage to a material that had been made at a much higher temperature. Applications that take advantage of this attribute have not been explored at this time.

5)Surface treatments

In order for the light weight brick to be used in an exterior application, such as the facing material of a building, the toughness of the surface has to be increased to the point that casual abrasion does not damage it. A glaze is a coating that is put on the material before it is sent to the furnace, in order to achieve a waterproof surface when it comes out. To this end, several kinds of glazing materials were tested to find which, if any, would work best on light weight brick to protect it from damage and/or seal it from the weather. In addition, several post-firing materials were tried.

For the test of traditional glazing materials a large block (2" x 6" x 40") of light weight brick was made and fired. Onto this pre-fired block several glazes were brushed in swatches across the width of the block and several inches long:

Grey Englobe Specific Gravity 1.5
- Brick white
- MnO_2 (3%)
- Calgon
- Kelzan

Grey Englobe with sand mix
- as above
  - Silica
  - Naph Syn
  - Feldspar

Grey Englobe Specific Gravity 1.36
- as above

Clay Specific Gravity 1.55
- 50% Red art
- 50% Gold art
- 1% Calgon

Clay with sand mix
- as above

100% Gold art clay	Specific Gravity 1.7
Umber	Specific Gravity 1.45

The material was then sent into the kiln for firing.

When it came out of the kiln, the light weight brick showed little evidence of having been glazed at all. Nearly all of the various glazes had been sucked into the brick by capillary action and so dissipated. Very little remained on the surface, and the surface area that had been glazed was no stronger than the other faces of the block. The umber darkened the color of the block, but had no other effect.

A test of a low temperature glaze (400 F) was made on a fired piece of light weight brick. This glaze was supposed to resemble ceramic glazes and to be waterproof, but had much less strength. The glaze was placed on the material in amounts ranging from thin to nearly twice the recommended thickness (according to instructions). The piece was then heated to 400 F for one-half hour. At the end of that time the glaze had either disappeared into the material or had beaded, according to the thickness of the original placement, but had not coated the surface.

A test of paint was also tried to see if the pores could be sealed by a quick drying material. Black spray paint was applied very thickly to one half of a block and allowed to dry. The paint was sucked into the block almost immediately leaving a thin blackish film behind. A second application of paint was then made and allowed to dry. The end result is a material of blackish brick color, of no noticeable increase in strength over the unpainted half of the block, and without sealing the pores.

A small piece was made and a coating of plain clay put on one side before firing. The shrinkage of the material caused the clay coating to crack and buckle instead of forming a seal, as it had a different shrinkage rate.

Liquids or materials that become liquid during processing will be drawn into this material and so cannot be used to seal the surface. A solid or semi-solid material that can be applied post-firing is needed to seal the surface and possibly to increase the surface strength. Exterior plaster or adobe or similar materials should work.

6)Adhesion

To add strength to a building system that incorporates light-weight brick it may be necessary to form it into composite panels. Several tests were therefore made to see how the material would adhere to a base of wood. The adhesives tested were Elmers wood glue, construction adhesive, and epoxy. All three bonded the light-weight brick to the wood very well as long as the block of material was clean and free of dust before the adhesive was applied. In no case did the bond fail. When the sample with construction adhesive was struck, creating a shear force across the bond, the light-weight brick failed outside the area of glue penetration, indicating that the bond is stronger than the material and that the material penetrated by the glue is stronger than both. Later accidents with the other adhesive-samples confirmed this. Capillary action pulled the glue into the pores creating a solid material from the semi-solid foamed material.

This ability to bond strongly indicates that the relatively fragile light weight brick could be strengthened by the application of a surface of a different, much tougher material such as wood, plastic, or aluminum sheeting. This type of composite system would be practical for the interior walls of buildings, or inside exterior walls, where fire-proofing and/or insulation is necessary.

7) Freeze-thaw

Any material exposed to freezing weather has the potential of damage from the expansion of water as it changes to ice in cracks or holes in the material. Repeated cycles of thawing and refreezing can enlarge cracks and cause spalling of exposed surfaces. Iowa winters are especially hard on materials as this cycle can take place every day throughout the season. A piece of this material approximately 8" x 8" x 2" was left outside in open air for five+ years. At the end of this time the material shows no damage from spalling and is as solid as a piece that was not exposed. This material seems to be so porous that the water has plenty of room to expand inside the pores that the structure of the ceramic is not damaged.

CONCLUSION

Clay as a building material has a history as long as human civilization. Recent technological advances such as steel construction have reduced the impact of brick while others have increased the variety of ceramic products available to builders. This light-weight brick material could be a valuable addition to these products.

Operating on the hypothesis that a light-weight brick material could be developed based upon Brosnan's original formulae, my experimental procedure for producing a light weight brick material were outlined. A description of clay materials was provided, and a history of such materials employed in brick making was reviewed. Experimental processes were then described, with explication upon choices for materials and manufacturing processes.

The Gradient Kiln tests showed the best range of temperatures to burn each type of clay - that being the same range as bricks made with that clay, which showed that clays with known firing ranges could be used in this application without testing beforehand. Compression tests revealed that finer-grained bricks were stronger than coarser grained products and gave some indication for which uses this material might work best. Heat tests indicated that light-weight bricks had insulative values comparable to those of insulation board, but were far less likely to be fire-damaged as they could withstand temperatures of 2000 F without damage. Tests on the capillary action of my brick products show that these light-weight bricks are highly absorbent, able to increase their weight by more than 50% through water absorption, and readily soaking up other materials such as lamp oil, glazing, and paint.

The ease of its ability to be molded and shaped after firing will be a great advantage for an inner wall insulator. It can be cut to fit any around any obstruction, and can be routed out to allow for electrical boxes and wires or other innerwall systems. Furthermore, it will not melt in a fire like foam insulation does, giving off noxious fumes, nor will it throw splinters like fiberglass does.

This all indicates that light-weight brick material can be made in large scale operations without altering the kiln, or in small or even individual kilns for home use. The ease of mixing combined with the ease of fabrication after firing makes this material ideal for people concerned about chemicals in the home environment, but who still want good insulation and fireproofing.

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APPENDIX

Lab NoteBook

Nos. 1-7 conducted without me

8 7-31-90

Clay (Endicott)	160g
Plaster of Paris	641g
Fly Ash	1248g
Air Entrainment	3g
Water	3000g

specific gravity 1.18
high fly ash - foam on top - need to increase clay percentage
made 3 bricks, #1 with batch 11 on top. dumped foam off top after 30 minutes.
oven dry, kiln test.
very fragile, good weight

9 7-31-90

Clay (Endicott)	1815.0g
Plaster of Paris	96.0g
Fly Ash	789.0g
Air Entrainment	2.9g
Water	2440.0g

made mistake in plaster of paris - no set
formed in plastic cylinder mold, in drying room all night, dumped from cylinder in the morning, the bottom hadn't dried, it was fairly stiff - no slump.

10 7-31-90

Clay (Endicott)	1816.0g
Plaster of Paris	454.0g
Fly Ash	454.0g
Air Entrainment	.7g
Water	2000.0g

sluggish set
looked like Clemsen lab batches - decided to increase PofP in next
formed in cardboard cylinder. in drying room all night, dumped in the morning.
consistency good - shrinkage even top to bottom, still wet.

11 7-31-90

Water	4000.0g
Air Entrainment	.6g
Plaster of Paris	1362.0g
Fly Ash	0g
Clay (Endicott)	4540.0g

normal set
formed in plastic cylinder, sent back to Ames with me.
tipped over at Endicott, shoved back in cylinder, 5 hours vibrated in car - little noticeable settling. set on porch until 8-7-90. 1/2 came out in a lump - still wet, but with a set. the rest was scooped out and flattened on newspaper to dry. consistency of cake frosting. 8-30-90 took them back to Endicott for firing. They both broke up with firing, nothing much left.

12 7-31-90

Water	5000.0g
Air Entrainment	1.1g
Plaster of Paris	1702.0g
Fly Ash	0g
Clay (Endicott)	5788.0g

specific gravity 1.73
looked normal but specific gravity was high.
formed in waffle block + 1 brick.
waffle sent to hive kiln to dry, shrank from 12" to 10 7/8", small cracks some not so small, cups came out easily, but it wasn't completely dry in the center.
sliced brick into 2 blocks and 2 slabs, added hatching to measure shrinkage, sent to test kiln. 1" shrank to 13/16", 2" shrank to 1 11/16". underfired

This series was a failure. Using Plaster of Paris, nothing set up properly.

13 9-13-90

Clay (Endicott)	400.8g
Gypsum Cement	39.0g
Air Entrainment	.6ml
Water	300ml

formed in paper cup.

14 9-13-90

Clay (Endicott)	250.9g
Gypsum Cement	49.5g
Air Entrainment	.5ml
Water	220.0g

formed in brick

15 9-13-90

Clay (Endicott)	903.0g
Gypsum Cement	250.0g
Air Entrainment	.3ml
Water	800.0g

formed in 2 bricks
solider going into mold. GC was added at last minute.

16 9-13-90

Clay (Endicott)	3180.0g
Gypsum Cement	720.0g
Air Entrainment	1ml
Water	3000.0g

17 1-24-91

Clay	202.2g
Cal LS	25.2g
Fly Ash	63.4g
Water	300.0g

solid in 5 days, but fly ash sank to bottom - bad mix, maybe too much water

18

Clay	202.2g
Cal LS	25.2g
Fly Ash	63.4g

mixed dry ingredients first
probably added too much water - about 2 cups
set in 2 days
solid in five
fly ash sank to the bottom - not good mix

Start new series

1 1-10-91

Clay (Adel)	75%
Gypsum Cement	25%

mixed in large barrel with oar.
formed into 2' x 2' x 2" wooden box with ribs. ribs broke off prior to firing.
fired has lots of lumps of unmixed clay. gray-white color and easily marked. rather friable, broke into many pieces during firing.

2 1-10-91

Clay (Adel)	70%
Gypsum Cement	30%
large grain sawdust filler	

mixed in large barrel with oar.
formed into 2' x 2' x 6" wooden box.
fired has an odd layering, 1" yellow then 1.5" red then 1" gray-red then reverse. perhaps the calcium migrated to the exterior of the piece. about 1/4 of the block broke off from the rest.

3	1-31-91	
Clay		6950g
Cal. LS		572g
Water		4747g

dry ingredients mixed first
formed into 36" x 6" x 2" wooden box.
after 1 hour top is still soupy, has settled some - about 1mm below edge of form

4	1-31-91	
Clay		7000g
Fly Ash		7000g
Cal LS		1175g
Water		9500g

very thick stuff
36" x 6" x 2" form, 12" x 12" x 1" form
6" x 6" x 12" form not entirely filled

5	2-5-91	
Clay	28.57%	3600g
Fly Ash	28.57%	3600g
Cal LS	4.76%	600g
Water	38.00%	4800g

fly ash is still warm from the furnace
1' x 1' x 1" form poured
mix is thick, set is fairly quick

6	2-5-91	
Clay	28.57%	3600g
Fly Ash	28.57%	3600g
Cal LS	4.76%	600g
Water	38.00%	4800g

fly ash is cool for this test
after 1/2 hour it is still quite wet and though I was supposed to take it right down and put it in the dryer, I can't move it because of the viscosity. I've set my desk lamp over it to maybe give it some heat to hurry it along.
the coolness of the fly ash is probably the reason for the difference in set time.

7 2-5-91

Clay	1200g
Fly Ash	1200g
Cal LS	200g
Water (hot)	1600g

set up pretty good
filled two 8" x 8" x 1.5" pans (Aluminum)
one lined with newspaper to prevent sticking, the other not
put lined pan under heat lamp

8 2-7-91

Clay	1400g
Fly Ash	1400g
Cal LS	210g
Water (hot)	1400g

two 8" x 8" x 1.5" pans, both lined
the mix was very thick - rather like pudding
had to scoop it out - it wouldn't pour
set one under heat lamp immediately

9 2-12-91

Clay	800.0g
Fly Ash	800.0g
Cal LS	120.0g
Fibers	3.5g
Water (hot)	800.0g

mixed dry then added water
fibers are the same as is added to cement to get a stronger concrete
8" x 8" x 1.5" pan, lined
covered pan with plastic to keep steam in and then put in under a heat lamp
this one did not crack before it solidified

10 2-14-91

Clay	800g
Fly Ash	800g
Cal LS	200g
Water (hot)	800g

fairly good mix
8" x 8" x 1.5" pan, lined and covered
put in heat, one hour later still not set but thicker

11 2-15-91

Clay	800g
Fly Ash	800g
Cal LS	200g
Water (cold)	400g
Vinegar	200g

8" x 8" x 1.5" pan, lined
came out thick and set quickly, but not as much volume as I normally get

12 2-19-91

Clay	800g
Fly Ash	800g
Cal LS	200g
Fibers	5g
Water (hot)	600g
Vinegar	200g

8" x 8" x 1.5" pan, lined
topped with clay-vinegar slurry to see if I can get a solid face
300g clay + 90g vinegar
set up really fast - must be the vinegar

13 2-21-91

Clay (fine ground)	800g
Fly Ash	800g
Cal LS	200g
Sawdust (fine)	180g
Water (hot)	600g
Vinegar	200g

8" x 8" x 1.5" pan, lined
started thickening before I had all the sawdust in
next time add more water
marked for shrinkage

14

Clay	800g
Fly Ash	800g
Cal LS	200g
Sawdust	300g
Water (cold)	970g
Vinegar	200g

8" x 8" x 1.5" pan, lined
far too stiff too quickly
the sawdust is a fault
volume half again as much as usual

15

Clay	800g
Fly Ash	800g
Cal LS	200g
Sawdust	150g
Fibers	3g
Water (cold)	800g
Vinegar	200g

8" x 8" x 1.5" pan, lined
poured relatively thin and light
solid in 20 minutes

16

Clay	800g
Fly Ash	800g
Cal LS	200g
Sawdust	250g
Fibers	3g
Water	1000g
Vinegar	250g

1" x 12" x 12" form, lined
5:45 poured
6:20 quite stiff, not up to moving yet
7:05 still not up to moving
8:00 stiff

Harold Newman (Endicott) took it and fired at cone 1
reclaimed 4-2-91.
broken - piece is .75" x 4.5" x 5.5" and 215g
= 44 lb per cubic foot

17

Clay	800g
Fly Ash	800g
Cal LS	200g
Sawdust	150g
Fibers	3g
Water	1000g
Vinegar	250g

8" x 8" x 1.5" pan, lined to get added height to 2"
mixed fast, thickened faster
6:00 poured
6:20` quite stiff, not up to moving
7:05 put in lamp heat
marked for shrinkage 4"
dry weight 1446.5g
approximate dry size 1.9" x 7.5" x 7.5"

18

Clay	1600g
Cal LS	200g
Water	800g
Vinegar	200g

no good, wouldn't set

19

Clay	1200g
Fly Ash	400g
Cal LS	200g
Water (hot)	800g
Vinegar	100g

6-5-91 meltdown test
149g dry before test
3pm total immersion
leave overnight
almost no mass loss

20

Clay (Endicott)	800g
Fly Ash	800g
Cal LS	200g
Sawdust	100g
Water	1000g
Vinegar	200g

reclaimed 4-2-91
large cracks, shrinkage about 7%
not flaky, color good
7" x 7" x 1.33" and 1249g
= 72.9 lb per cubic foot

21

Clay (Adel)	800g
Fly Ash	800g
Cal LS	200g
Water (hot)	700g
Vinegar	215g
Soap	5g

9 small samples for David Dalquist (ceramics prof)

22

Clay (Adel)	1200g
Fly Ash	400g
Cal LS	150g
Water (hot)	800g
Soap	5g

23

Clay (Adel)	400g
Fly Ash	250g
Gypsum Cement	350g
Water	760g
Sawdust	?

8" x 8" x 1.5" pan
still set, but damp
marked for shrinkage 4" and 6"
after fire shrinkage 4/3.87
1935 F - overcooked - slag marks

24

Clay	1000g
Fly Ash	600g
Cal LS	150g
Water (hot)	800g
Soap	14g

too dry, needs more water
no good set

25

Clay (Adel)	1000g
Fly Ash	600g
Cal LS	150g
Sawdust	74g
Water (hot)	1000g
Soap	20g

liquid soap didn't help - wouldn't foam

26

Clay (Adel)	400g
Fly Ash	300g
Gypsum Cement	300g
Sawdust	100g
Water	800g

1935o F partially slagged
poor color

27

Clay	1000g
Fly Ash	600g
Cal LS	150g
Sawdust	70g
Fibers	5g
NaSil	10g
Water (hot)	1000g

sodium silicate is a liquid added to bricks to help prevent shrinkage

28

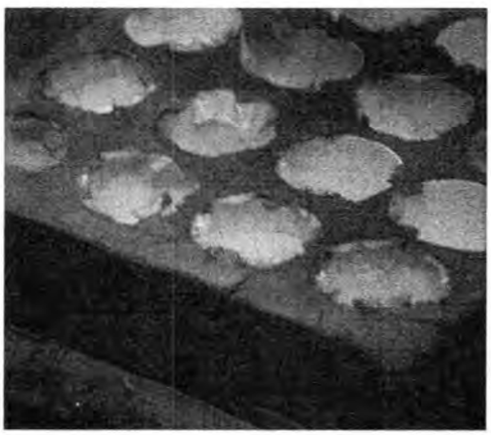
Clay	400g
Fly Ash	300g
Gypsum Cement	300g
Fibers	3g
Sawdust	155g
NaSil	5g
Water	800g

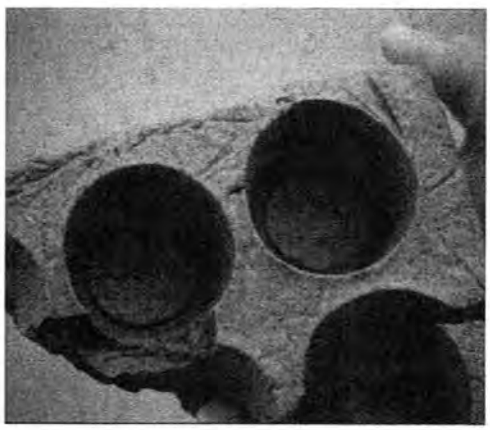
1935 F
good sound where it's not melted through
quite fragile and soft
color ok

29 4-17-91

Clay (Adel)	3000g
Fly Ash	1800g
Cal LS	450g
Fibers	15g
NaSil	30g
Water (hot)	3000g

6" x 6" x 12" with holes for waffle effect





30	
Clay (Adel)	2000g
Fly Ash	1200g
Cal LS	300g
Sawdust	400g
Fibers	6g
NaSil	60g
Vinegar	400g
Water (cold)	2000g

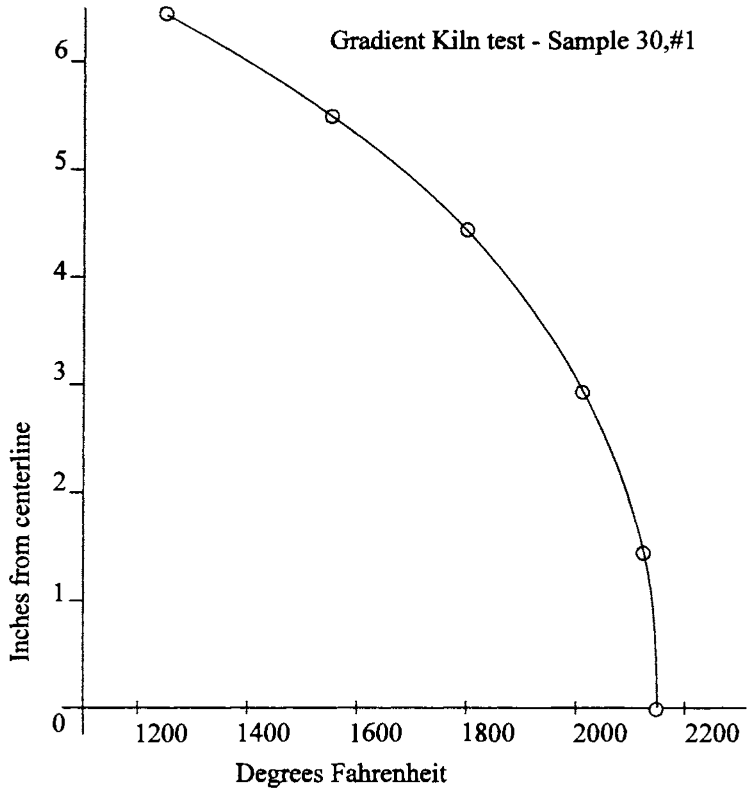
made 2 pieces for Bruce's class
4.5 lb each 98 cubic inches
3.5 lb each after cooking - very little shrinkage 62 lb per cubic foot

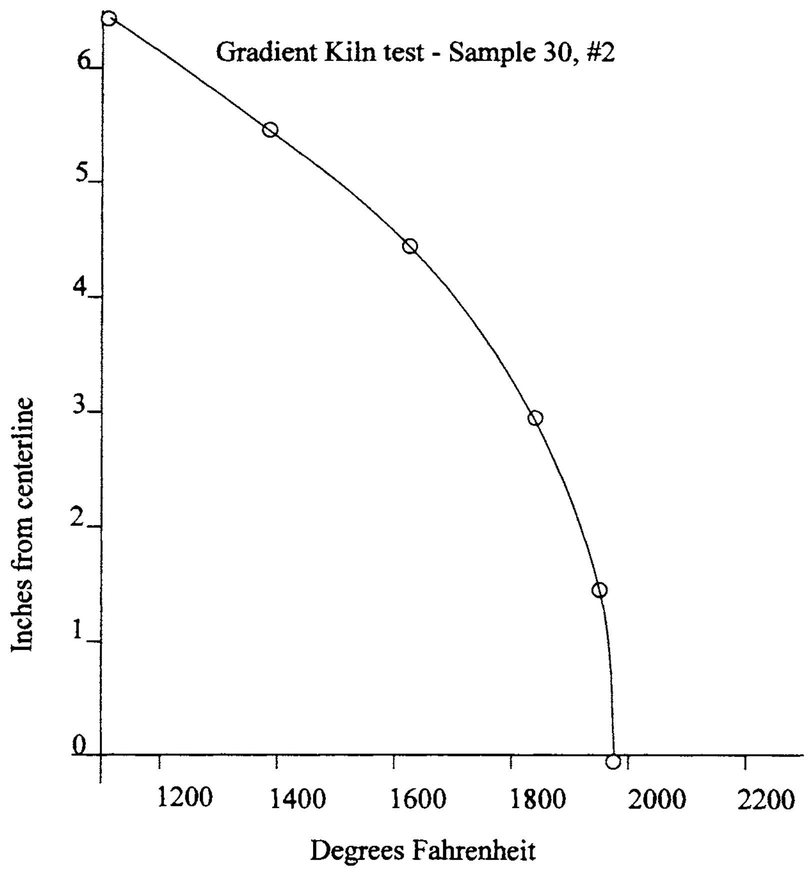
gradient kiln test - slow cool

distance to center	degrees C	soft all through entire length
4.5	925	
3.0	1060	
1.5	1145	
0	1175	
1.5	1160	
3.0	1100	
4.5	985	
5.5	840	
6.5	670	

gradient kiln test

distance to center	degrees C	at no point did this become a
0	1080	solid before it vitrified
1.5	1065	it seems Adel clay is
3.0	1000	unsuitable for this
4.5	880	application
5.5	750	it will not become a solid
6.5	600	mass at any temperature


Gradient Kiln test - Sample 30,#1
Inches from centerline
0
1
2
3
4
5
6
1200
1400
1600
1800
2000
2200
Degrees Fahrenheit


Gradient Kiln test - Sample 30, #2
Inches from centerline
0
1
2
3
4
5
6
1200
1400
1600
1800
2000
2200
Degrees Fahrenheit

31

Clay (Endicott)	1000g
Fly Ash	600g
Cal LS	200g
Fibers	3g
NaSil	15g
Water	1200g

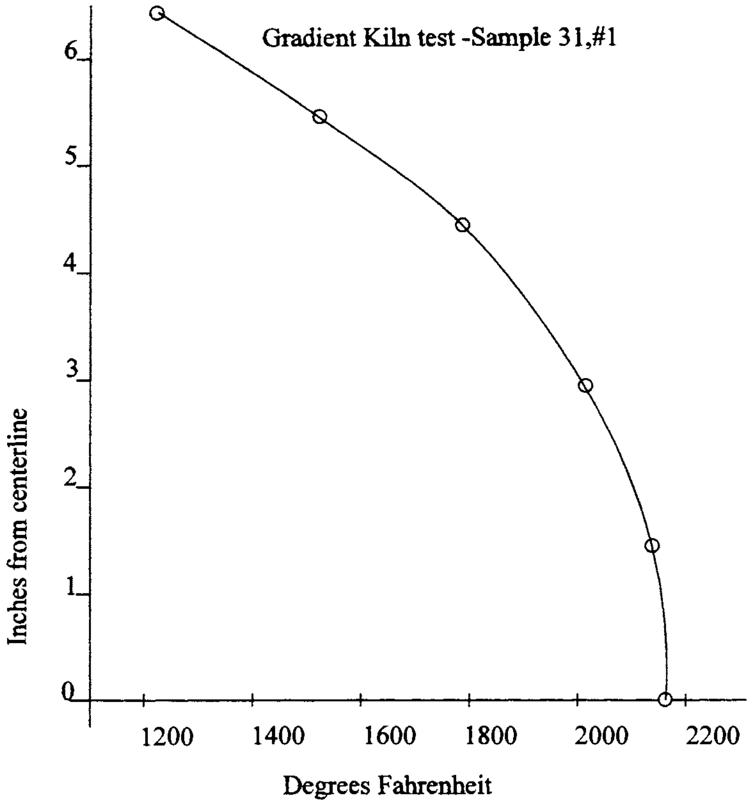
Gradient kiln test
6-11-91 Gradient kiln test

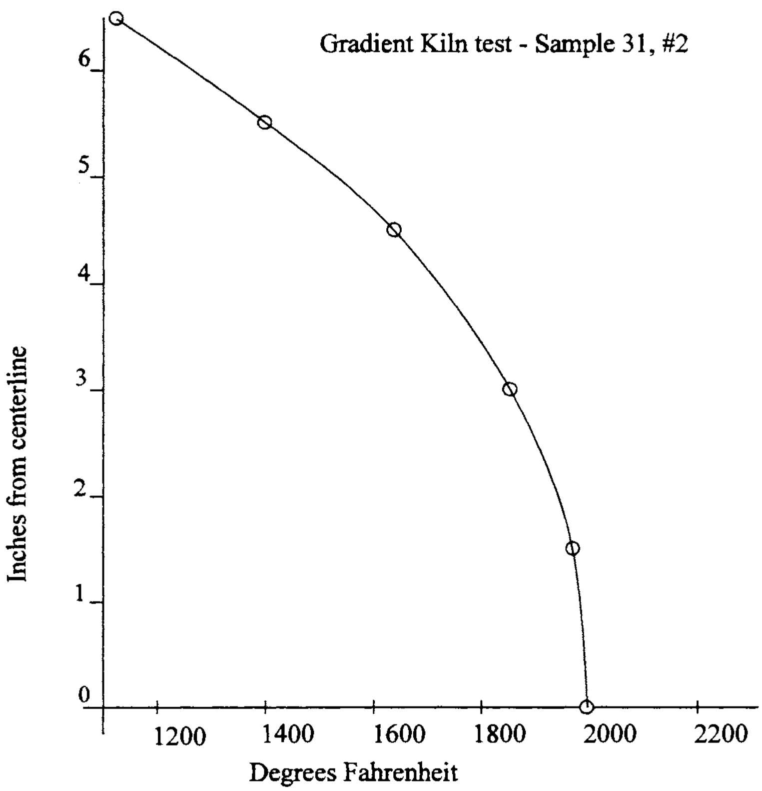
distance to center	degrees C	
3.0	1070	removed from kiln too quickly after firing, fast cool shattered sample
1.5	1145	
0	1180	
1.5	1165	
3.0	1100	
4.5	980	
5.5	830	
6.5	660	

gradient kiln test - slow cool

distance to center	degrees C	
1.5	1050	interior about 5 3/4" sounds best
0	1090	color ok, hardness ok
1.5	1075	below 5" soft, undercooked
3.0	1010	at 7" color becomes bad, softness increases
4.5	890	
5.5	760	
6.5	610	

best at about C 1050 to C 1100
that is F 1900 to F 2000
much better results than Adel clay. Endicott clay includes grog (broken bits of fired brick)


Gradient Kiln test -Sample 31,#1
Inches from centerline
0
1
2
3
4
5
6
1200
1400
1600
1800
2000
2200
Degrees Fahrenheit


Gradient Kiln test - Sample 31, #2
Inches from centerline
0
1
2
3
4
5
6
1200
1400
1600
1800
2000
2200
Degrees Fahrenheit

32

Clay (Endicott)	1000g
Fly Ash	600g
Cal LS	200g
Sawdust	300g
Fibers	3g
NaSil	22g
Water (hot)	1600g

half

33

Clay (Endicott)	1000g
Fly Ash	600g
Cal LS	200g
Sawdust	300g
Fibers	3g
NaSil	22g
Water (hot)	1600g

half of 32
let set 2 days before heating and solidifying

34

Clay (Endicott)	1000g
Fly Ash	600g
Cal LS	200g
Sawdust	300g
Fibers	3g
NaSil	28g
Water (hot)	1800g

very thin and runny
more than enough for 12" x 12" x 1" form
set under heat lamp - starts setting up within 5 minutes

35
remainder of 34
about 1/4

36 10-7-92

Clay (Endicott)	1000g
Fly Ash	600g
Sawdust	300g
Fibers	3g
Cal LS (liquid)	400g
Water (hot)	1400g

12" x 12" x 1" form, lined with plastic wrap
in oven 200 F for 3 hours
cool for 12 hours
still damp and soft
dry with heater

37 10-8-92

Clay	100g
Fly Ash	600g
Sawdust	300g
Fibers	3g
Cal LS (liquid)	400g
Water (hot)	1400g

12" x 8" x 2" form with ribs
mold unlined but soaked in water, to prevent drying before set
dry at 250 F
shrinkage bad and form warped - don't do it again

38

Clay	1000g
Fly Ash	600g
Sawdust	300g
Cal LS	200g
Water (hot)	1600g

8" x 8" x 2" form, lined
5" x 3" cylinder, lined
set up good
dry 2 hours at 250 F
continued drying 2 days - good set

39 10-20

Clay (Adel)	4000g
Fly Ash	2400g
Cal LS	800g
Sawdust	1000g
Fibers	12g
Water (hot)	6400g

6" x 40" x 2" form
5" x 3" cylinder
8" x 6" cylinder
8" x 8" x 2" pan
mixing bit on drill had hard time with this volume
mix a bit wet
cylinders and small pan into oven to dry
large pan on floor until set - about 10 minutes
then placed in sun under black tarp to keep in heat
the Cal LS in the water leaked out the bottom of the form all over the floor

40 10-22

Clay (Council Bluff)	1000g
Fly Ash	600g
Cal LS	200g
Sawdust	300g
Fibers	3g
Na Sil	30g
Water (hot)	1600g

Council Bluff clay includes grog and is coarse ground

gradient kiln test

distance to center	degrees C	good color at about 1 inch, vitrification at .75 inch
0	1085	
1.5	1065	
3.0	990	
4.5	850	
5.5	710	
6.5	550	

41 11-5

Clay	2500g
Fly Ash	1500g
Cal LS	500g
Sawdust	750g
Fibers	8g
NaSil	75g
Water	4800g

screwed up somehow
real wet - no good for cylinder

42

Clay	1800g
Fly Ash	450g
Cement	450g
Fibers	2g
Sawdust	150g
NaSil	2g
Water	2000g

slow set
red gray color
8" x 8" x 2" and 3" x 5" cylinder
some settling occurred before set
try more cement next time
3" can tipped some by dog - no longer full
310g fully dry
d = 2.75"
h = 3.5"
never fired
after 5 years semiprotected (dry but exposed to cold) no change in characteristics

43

Clay (Council Bluffs)	1800g
Fly Ash	600g
Cement	600g
Fibers	3g
Sawdust	150g
NaSil	105g
Air Entrainment	1g
Water	2200g

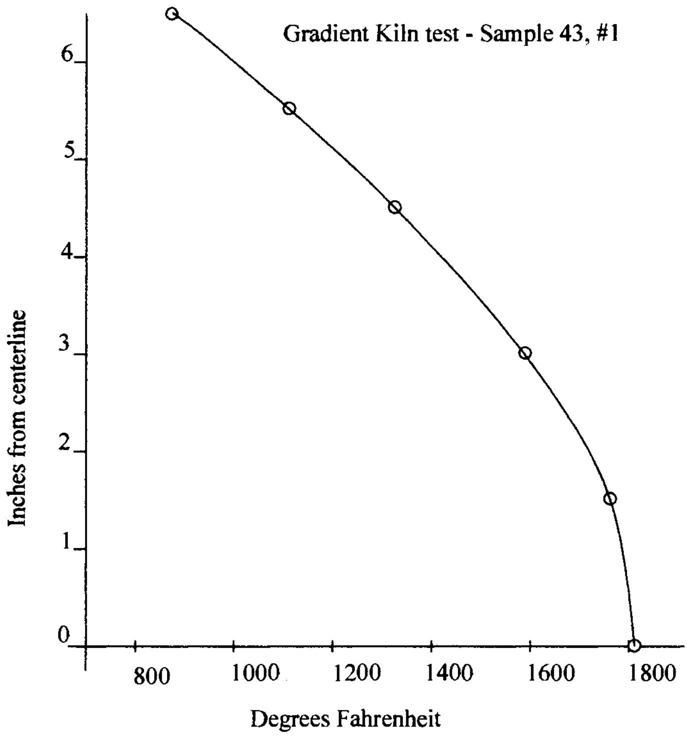
pretty good
set ok

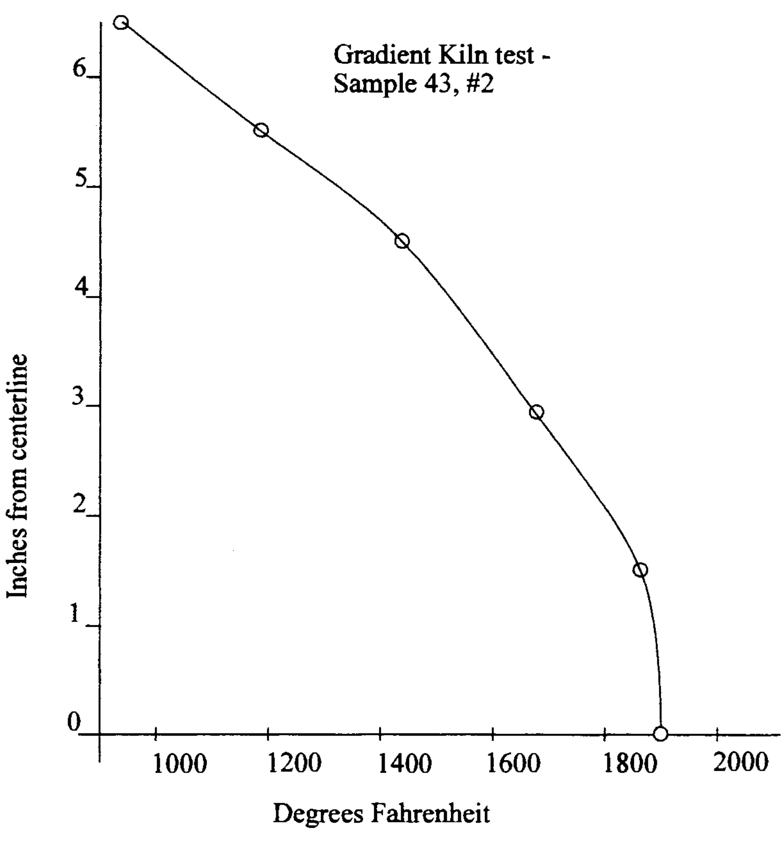
gradient kiln test #1

distance to center	degrees C	
6.5	990	didn't get as hot as I expected at centerline it is tough, but of a grayish color
5.5	960	
4.5	865	
3.0	725	
1.5	600	
0	470	

gradient kiln test #2

distance to center	degrees C	
6.5	1045	again bad color through out, it never did really get very tough, there was some vitrification at the centerline
5.5	1015	
4.5	920	
3.0	780	
1.5	640	
0	500	


Gradient Kiln test - Sample 43, #1
Inches from centerline
0
1
2
3
4
5
6
800
1000
1200
1400
1600
1800
Degrees Fahrenheit


Gradient Kiln test -
Sample 43, #2
Inches from centerline
0
1
2
3
4
5
6
1000
1200
1400
1600
1800
2000
Degrees Fahrenheit

44

Clay (Council Bluffs)	4500g
Fly Ash	1500g
Cement	1500g
Fibers	10g
Sawdust	700g
NaSil	20g
Air Entrainment	3g
Water (warm)	5500g

8" x 2" x 40" beam
sat on by Tinycat while drying - broken

45

Clay (Adel)	2700g
Fly Ash	900g
Cement	900g
Fibers	5g
NaSil	5g
Air Entrainment	1g
Water	3300g

12" x 6" cylinder
shrunk 1/2" - 3/4" from 12 " at 14 days
decanted solid but still very damp
dried skin over top kept water from getting out
after making this one, found section in literature that described the effects of fly ash on brick made in the 1770's. have decided that is the reason so many of my trials come back from the kiln yellowish and very soft instead of the red hard brickish things I expect.
#45, 46, 47 fired at same time
after firing - gray and very fragile

46

Clay (Adel)	2700g
Cement	900g
Fibers	5g
NaSil	5g
Air Entrainment	1g
Water	6400g
Sawdust to texture	

accidentally doubled water
will almost certainly shrink unacceptably
8" x 2" x 12"
12" x 12" x 1"
6" x 6" cylinder
after firing - softish but came out in single chunk

47

Clay (Adel)	2400g
Cement	900g
Water	3600g

after firing - pretty good but exploded in kiln - too much water still inside
need to get interior water out - need pores

48

Clay (Adel)	2400g
Cement 800g	800g
Fibers 10g	10g
Sawdust 475g	475g
NaSil 5g	5g
Air Entrainment 1g	1g
Water 3600g	3600g

mixed to consistency of oatmeal
8" x 12" x 2"
12" x 4" cylinder
problem with plastic cylinders solved by drilling holes in bottom and running drip lines down outside of lining and through holes to weep out the extra water and so dry it better

49

Clay (Adel)	2400g
Cement	800g
Fibers	8g
Sawdust	700g
Water	3600g

need to see if extra chemicals are really necessary
8" x 8" x 2"
fired well, good color, no breakage, to be used for heat tests

50

Clay	3600g
Cement	1200g
Fibers	12g
Sawdust to consistency	
Water	4000g

12" x 6" cylinder
#50, 51, 52, 53, 54 fired at same time

51

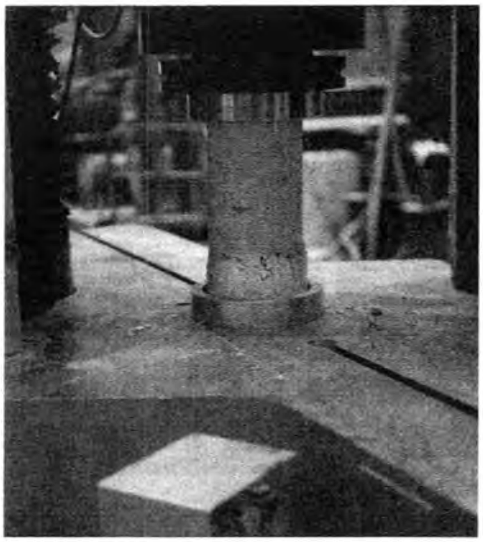
Clay	3300g
Cement	1600g
Fibers	11g
Sawdust	700g
Water (warm)	4000g

12" x 6" cylinder

52

Clay	2200g
Cement	1100g
Fibers	8g
Sawdust	500g
Water	3000g

8" x 12" x 2"
upon firing - good appearance but broken




53

Clay	3400g
Cement	1500g
Fibers	11g
Sawdust to consistency	
Water	4000g

12" x 6" cylinder, lined and with drip lines
broke upon firing

54

Clay	3600g
Cement	1200g
Fibers	12g
Sawdust to consistency	
Water	4000g

12" x 6" cylinder
Sawdust in this trial was of larger grain than usual.

Two cylinders #50 and #54 fired intact and were chosen for a crush strength test
#50 7.45 lb 10.5"h x 2.79"r a = 22.33 square inch
50.3lb/cubic foot
#54 11.5lb 11.5"h x 2.67"r a = 24.37 square inch
52.15lb/cubic foot
#50 4290lb peak pressure
#54 1830lb peak pressure
started breaking at bottom where it had slumped - possible weak points from too early removal from form.
#50 pressure = 176.04 lb/square inch
#54 pressure = 81.95 lb/square inch
not as good as I hoped
I wanted about 500lb
try it a little heavier - not so much water
#50 (small grain sawdust) is still in nice shape, though broken from the test
#54 (large grain sawdust) is crumbly at the break face
after 5 years these two cylinders present much the same appearance as immediately after test.

55 7-16-93

Clay (Adel)	3600g
Cement	1200g
Fibers	8g
NaSil	36g
Sawdust	1770g
Water	3600g

12" x 6" cylinder, lined and with drip lines
fired well - same appearance as without NaSil

56 9-6-93

Clay (Adel)	5400g
Cement	1800g
Fibers	12g
Cal LS	500g
Sawdust	1500g
NaSil	54g
Air Entrainment	1g
Water (hot)	6400g

6" x 2" x 40" slab
extra thick - possibly too much sawdust
when this slab was dry a variety of surfaces was applied
Gray englobe 1.5 Specific Gravity
Brick white, 3% MnO2, Calgon, Kelzan
Sandmix Silica sand, Naph syn, Feldspar
Gray englobe 1.36 Specific Gravity
50% red art, 50% gold art, 1% calgon - red sand on 1/2
1.55 Specific Gravity
100% gold art 1.7 Specific Gravity
Umber 1.45 Specific Gravity
none of these worked very well - most soaked in upon firing and were never seen again
the umber did change the color of the brick
The slab broke in several section, but was of good color and strength
I think there were several large pores that may have created stress points
also the stress of being moved about before it was completely dry may have stressed it.
stiffer forms are needed

Christmas 1993
took some broken but good pieces to Dad's to play with
tested 3 adhesives
Elmers wood glue
Liquid nail
Epoxy
didn't work if dust is not removed first
all three worked well
glued to unsanded wood blocks
three weeks later block with Elmers was knocked by dog. The wood broke. The Elmers had penetrated about 1mm into the brick and that had not broken.

Tried to make a solid surface on one side by vitrifiing the surface of a piece.
Used an acetelene torch to melt a section of the brick. A dime sized area of one chunk (about 2" x 2" x 2") melted to a greenish black. Since this stuff fires at about 2000F it must have gotten at least that hot. I picked it up not 5 second after Dad stopped the torch. The melt was 1 cm from the edge. I touched the side nearest the melt. It was warm but not hot. The heat had not penetrated 1 cm in 10 minutes of direct firing at 2000F.

We also decided to see if the capillary action I had described to Dad would work as well with oil as it did with water. Dad cut a chunk 1" x 1" x 2" approximately and set it in a beaker 1/2" full of lamp oil. In 15 minutes the oil had advanced to the top where Dad set it afire. It burned nicely, not damaging the brick at all, but we had to put it out as the flame was creeping down the sides of the chunk.